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SEEN AREAS AND THE DISTRIBUTION OF FIRES ABOUT A LOOKOUT

Romain M. Mees

Standard procedures for the evaluation of fire lookouts have been time consuming and frequently highly subjective. A computer simulation model for evaluating existing lookouts has been described in another paper (Mees 1976). In addition to using the computation of gross and net discovery indexes as explained there, the manager can analyze existing and proposed lookout sites using an estimate of the distribution of past fires with respect to distance from the lookout.

This report describes two programs available for this purpose. The programs, SEEN and HIST, are written in FORTRAN for operation on the IBM 360[1]. Copies of the programs are available upon request from the Director, Pacific Southwest Forest and Range Experiment Station, P. O. Box 245, Berkeley, California 94701, Attention: Statistical Services.

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[1] Trade names and commercial enterprises or products are mentioned solely for necessary information. No endorsement by the U.S. Department of Agriculture is implied.

Mees, Romain M.
1978. **Seen areas and the distribution of fires about a lookout.** Gen. Tech. Rep. PSW-26, 7 p., illus. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

From the location of a fire lookout and the sites of past fires within a given radius about a lookout, an estimate of the fire distribution with respect to distance from the lookout can be obtained. The estimated distribution can include all fires located within a given number of feet below the last maximum line of sight from the lookout. Seen areas for the same lookout can be developed, stored, and plotted at a computer site for future work.

Retrieval Terms: fire lookouts; evaluation; line of sight; simulation models; computer programs; SEEN; HIST.

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DISTRIBUTION OF FIRES ABOUT A LOOKOUT

In evaluating a lookout site, the distribution of historical fires about the site is examined with respect to distance from the lookout and distance below the last maximum line of sight from the lookout.

The procedure for determining the distribution is illustrated in *figure 1.* Here, fire 1 is directly visible; that is, it is in the seen area of the lookout because the angle measured between the horizontal and the fire 1 line of sight is less than the last applicable maximum line of sight—that is, angle α_1. The second fire location is not visible because the angle measured from the horizontal exceeds the angle α_1. Fire 3 is in a position similar to that of fire 2, whereas fire 4 is again directly visible and located in the seen area of the lookout.

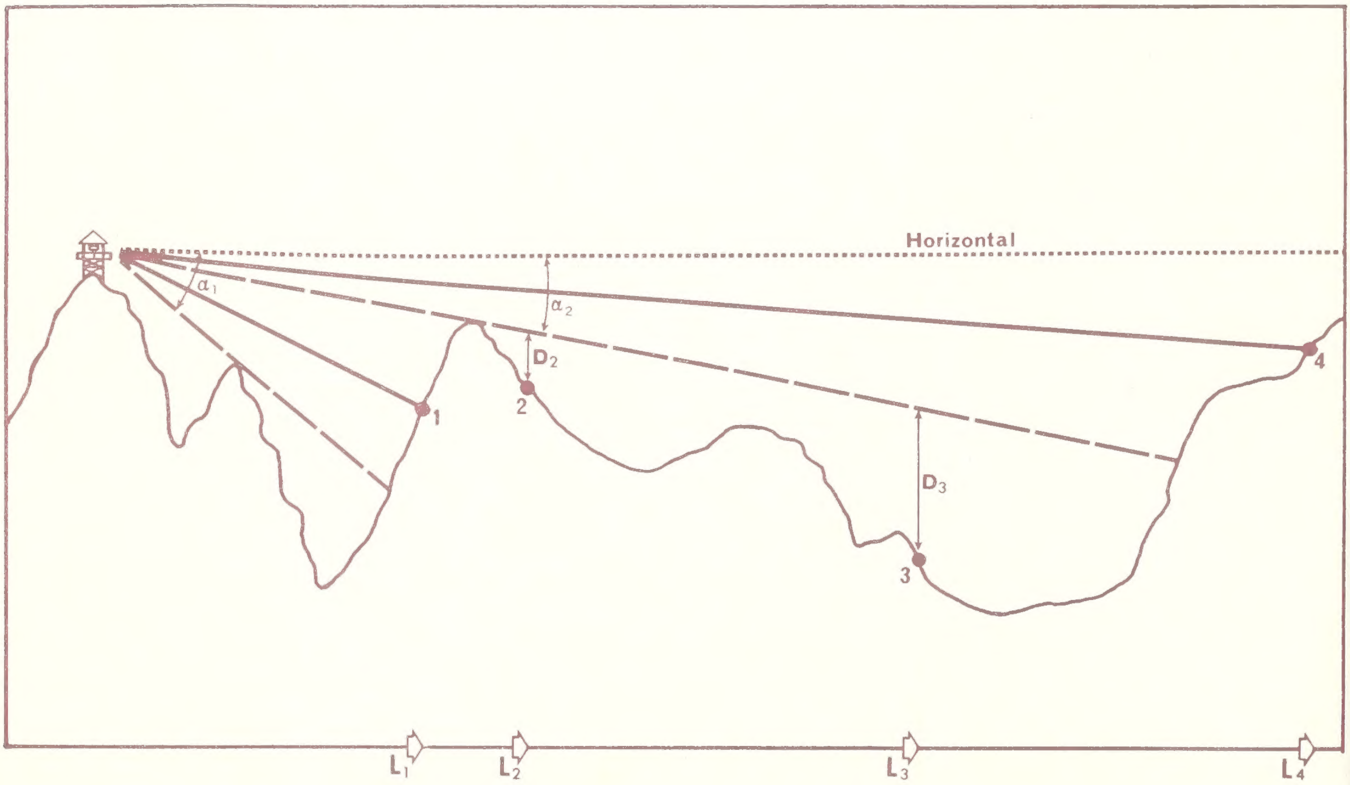


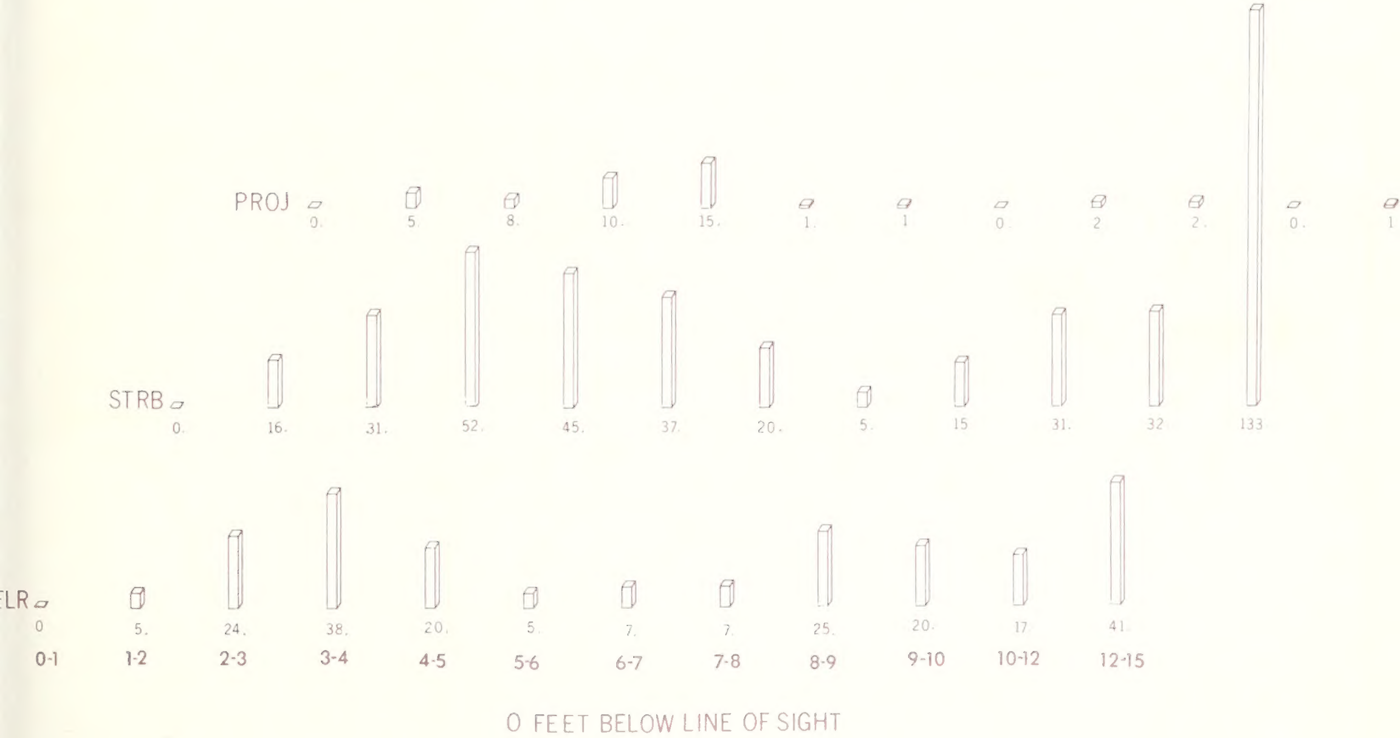
Figure 1—Fire locations 1 and 4 are in the seen area of the lookout. Fires 2 and 3 are below the last applicable maximum line of sight.

Although locations 2 and 3 are not directly visible, we can compute the vertical distances D_2 and D_3 shown in *figure 1.* The vertical distance D_1 is equivalent to the height of a smoke column needed for observation by the lookout. We also note that the fires are located at distances L_1 L_2 L_3 and L_4 from the lookout.

A computer program, HIST, has been developed to determine and plot all fires within a given distance either directly visible from the lookout or within some specified vertical distance D from the last maximum line of sight.

Historical fire data locations and topographic data for the San Bernardino National Forest are combined by program HIST, resulting in bar graphs (*figs. 2 and 3*).

As shown on the bar graph (*fig. 2*), 15 sites of past fires are in the seen area of the Project Peak lookout and within a distance of 4 to 5 miles (6.4-8 km); here the given vertical



Figures 2—The HIST program was used to produce this comparison between two existing lookouts (Strawberry and Keller Peaks) and one proposed site (Project Peak) for the years 1960 through 1969. Vertical column height represents the number of fires (indicated below the bar) located in 1-, 2-, and 3-mile circular increments about the lookouts for up to 15 miles (D = 0.0).

distance D = 0 feet. A similar graph for the Black Mountain lookout (*fig. 3*) with D = 200 feet shows 12 fires within 4 to 5 miles of the lookout and no more than 200 feet (61 m) hidden below the last maximum applicable line of sight.

The Project Peak lookout is a proposed site on the San Bernardino National Forest. The Strawberry and Keller Peak lookouts are operating lookouts for which the number of fires reported is known. Provided all local conditions are equal, the Project Peak lookout capability can be predicted by comparing the relative distributions.

Although the computed vertical distance D is highly dependent upon the accuracy of the lookout position and fire locations contained within the elevation data used, a good estimate of the distribution from the lookout and for a given vertical distance D can be obtained.

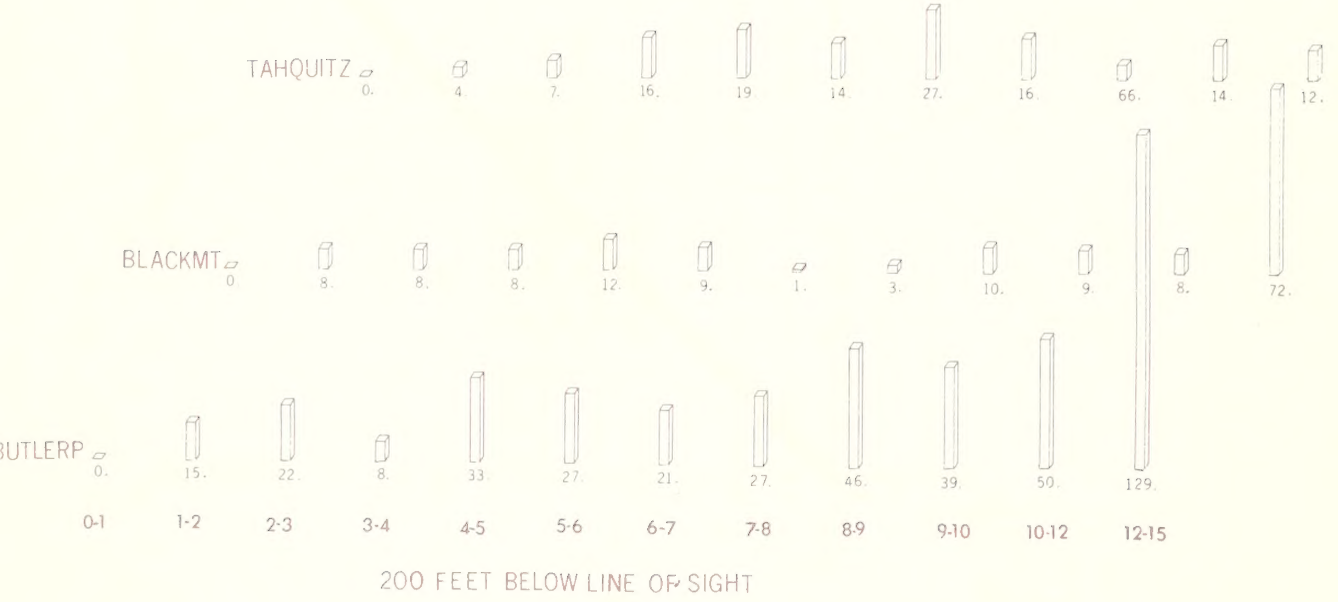


Figure 3—The HIST program was used to produce this summary of fire locations over the years 1960-69, for three lookouts (Butler Peak, Black Mountain and Tahquitz Peak) on the San Bernardino National Forest (D = 200 ft.).

SEEN AREAS

The same line-of-sight method and data can also be used to develop and plot seen areas for lookouts (Travis and others 1975). Again, the location and height of the lookout point must be combined with elevation data defined on a grid coordinate system as shown in *figure 4.*

Developing seen areas within a radius of 12 to 15 miles (19-24 km) of a lookout requires extensive elevation data and machine computation. To economize on both storage and computation, the SEEN program (Mees 1976) treats the area around the lookout one quadrant at a time, and takes advantage of the fact that all line of sight computations are identical, because of symmetry, with respect to the 45° line measured from the X-axis (*fig. 4*).

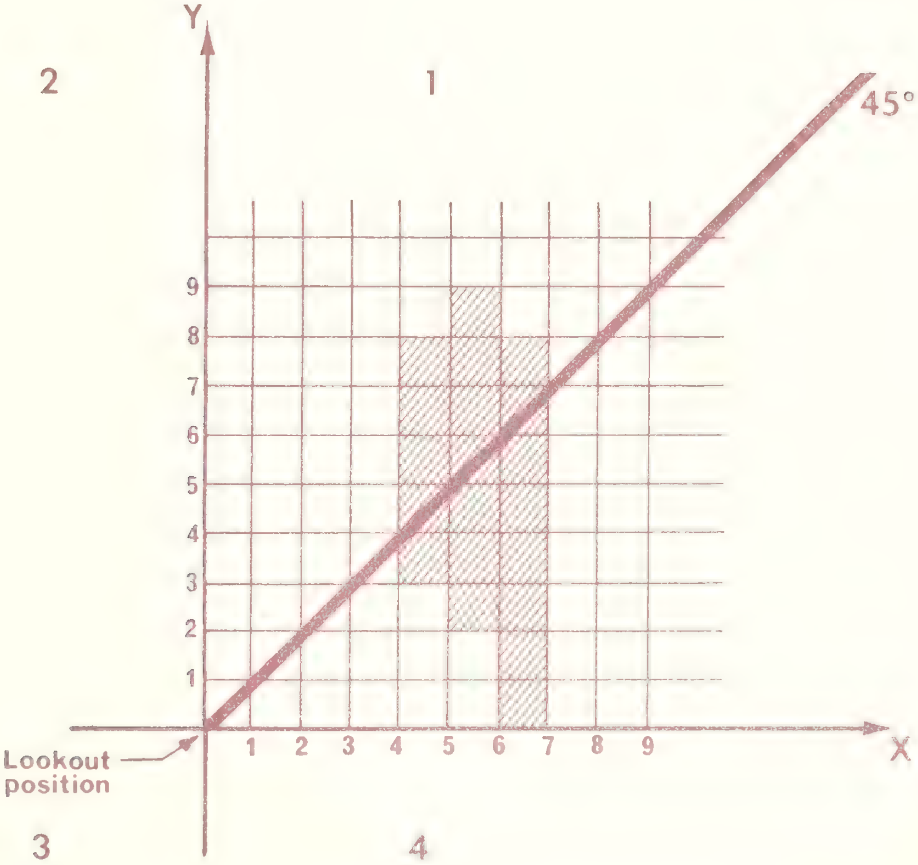


Figure 4—The area (shaded) seen from the detection point can be recorded by means of the values for the x and y axes and the number of visible squares. (Here the triplets are 4, 3, 5; 5, 2, 7; and 6, 0, 8.)

The seen areas produced by the SEEN program are plotted to any desired scale, usually 0.5 inch/mile, and are permanently stored at the computer site.

The SEEN program differs from existing seen area programs in that the program generates and retains a computer image of the seen areas for each lookout. The seen areas recorded can be used with a digital incremental plotter to produce a map overlay at any desired scale (*fig. 5*). The recorded seen areas can also be combined with fuel location data, wildland values, and other fire-related information for planning purposes. For example, the recorded seen areas have been combined with fire intensity areas to develop discovery indexes[2] for each lookout on the planning unit (Mees 1976).

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[2] U.S. Forest Service. 1971. *National fire planning instructions.* final ed., 70 p., Washington, D.C.

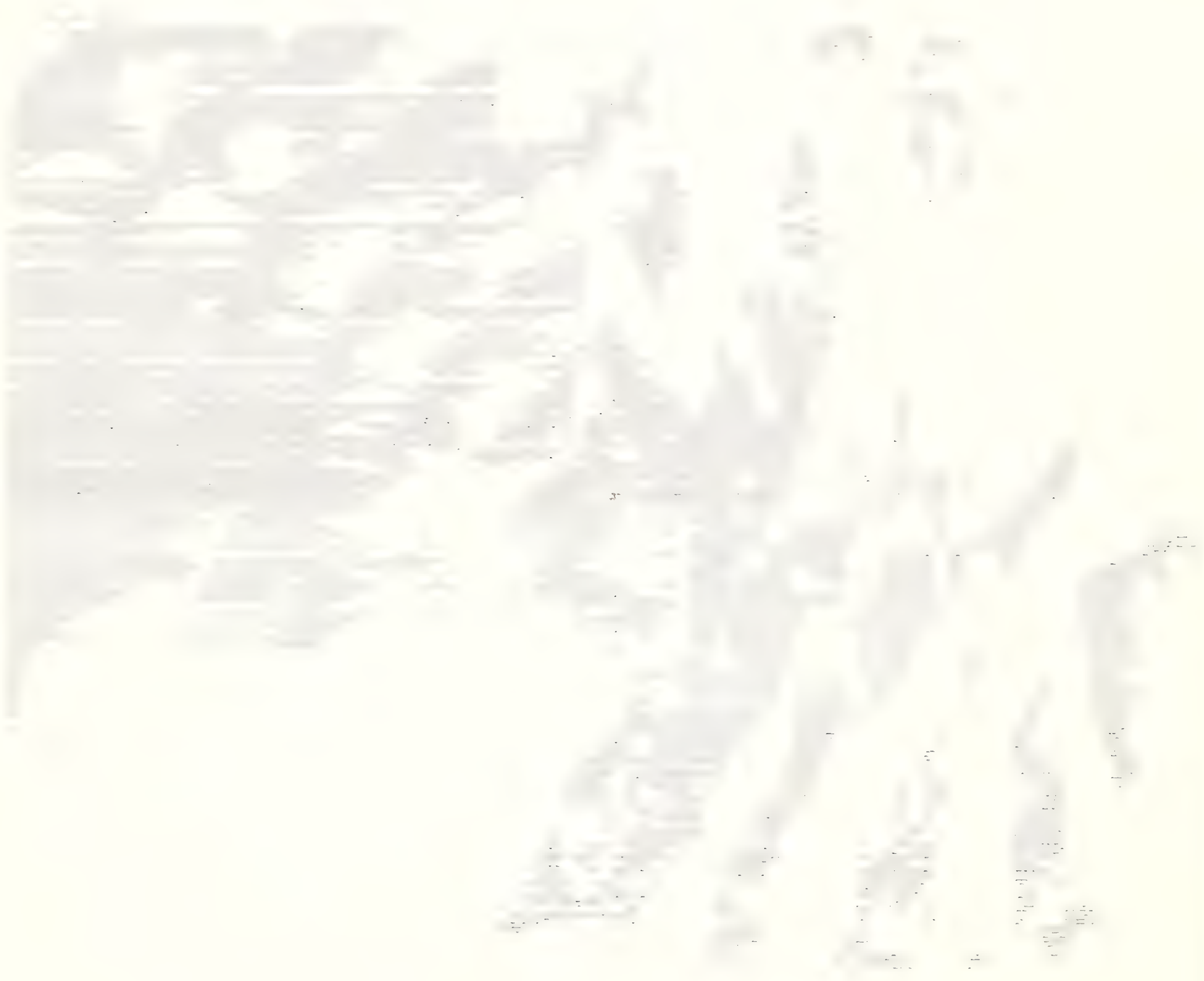

Figure 5—Partial seen area for the Summit lookout—San Bernardino National Forest (scale 0.5 inch/mile).

LITERATURE CITED

Mees, Romain M.
1976. **Computer evaluation of existing and proposed fire lookouts.** USDA Forest Service Gen. Tech. Rep. PSW-19, 6 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Travis, Michael R., Wayne D. Iverson, Gary H. Elsner, and others.
1975. **VIEWIT: computation of seen areas, slope and aspect for land use planning.** USDA Forest Service Gen. Tech. Rep. PSW-11, 70 p., Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

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COMPUTING ARRIVAL TIMES OF FIREFIGHTING RESOURCES FOR INITIAL ATTACK

Romain M. Mees

A national forest or planning unit consists of a variety of valuable assets to be protected by local fire agencies. In addition to these valued assets, and because of their importance to us, we have provided public road systems and firefighting resources.

The dispatcher of these resources to local fires must make instantaneous or precalculated decisions when a fire occurs in a given area. On smaller protection units, or those with few resources, travel times and resource availability are usually quickly available from personal knowledge, or from inspection of maps and other fire planning aids. If several protection agencies and many alternative resources are involved, choosing the "right" units for a particular fire dispatch is more difficult and time consuming.

This report describes a computer model for computing arrival times of firefighting resources for an initial attack on a fire. The model was developed to assist the fire dispatcher with the allocation of available resources quickly and efficiently.

The model requires a low-speed interactive terminal, available 24 hours, which the dispatcher can use to request a computerized list of possible resource arrivals on any fire within his area of responsibility. The resources are listed in order of arrival times, allowing the dispatcher to choose one or more resources to the fire location. The actual selection of resources from the listing will depend on local fire conditions and resource availability.

Mees, Romain M.
1978. **Computing arrival times of firefighting resources for initial attack.** Gen. Tech. Rep. PSW-27, 5 p., illus. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

Dispatching of firefighting resources requires instantaneous or precalculated decisions. A FORTRAN computer program has been developed that can provide a list of resources in order of computed arrival time for initial attack on a fire. The program requires an accurate description of the existing road system and a list of all resources available on a planning unit.

Retrieval Terms: Fire management, fire suppression programs; computer programs; simulation; travel time.

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Two data files, describing the road system used by the planning unit and the resources available to the unit, must be kept at the computer site *(fig. 1)*. The road network must be defined in terms of initial attack travel times between selected points (nodes) and all resources must be identified by name, getaway time, location, and average airspeed for air units. At the time the dispatcher requests a list of resource arrivals, he will need to specify the location of the fire in terms of longtitute and latitude coordinates, the maximum initial attack time, and the off-road travel speed to approach the fire on foot.

ALLOCATION PROGRAM

The allocation program determines the total time required to reach a fire as follows:

a. For helicopters and fixed wing aircraft, the getaway time (delay) is added to the time required to fly in a straight line to the fire, using an average cruise speed.

b. For ground units, a search algorithm computes the shortest time-route to the fire.[1] This time includes

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[1] Hillier, Frederick., and Gerald Lieberman. 1974. **Operations research.** p. 217, 220. Holden-Day, Inc. San Francisco, Calif.

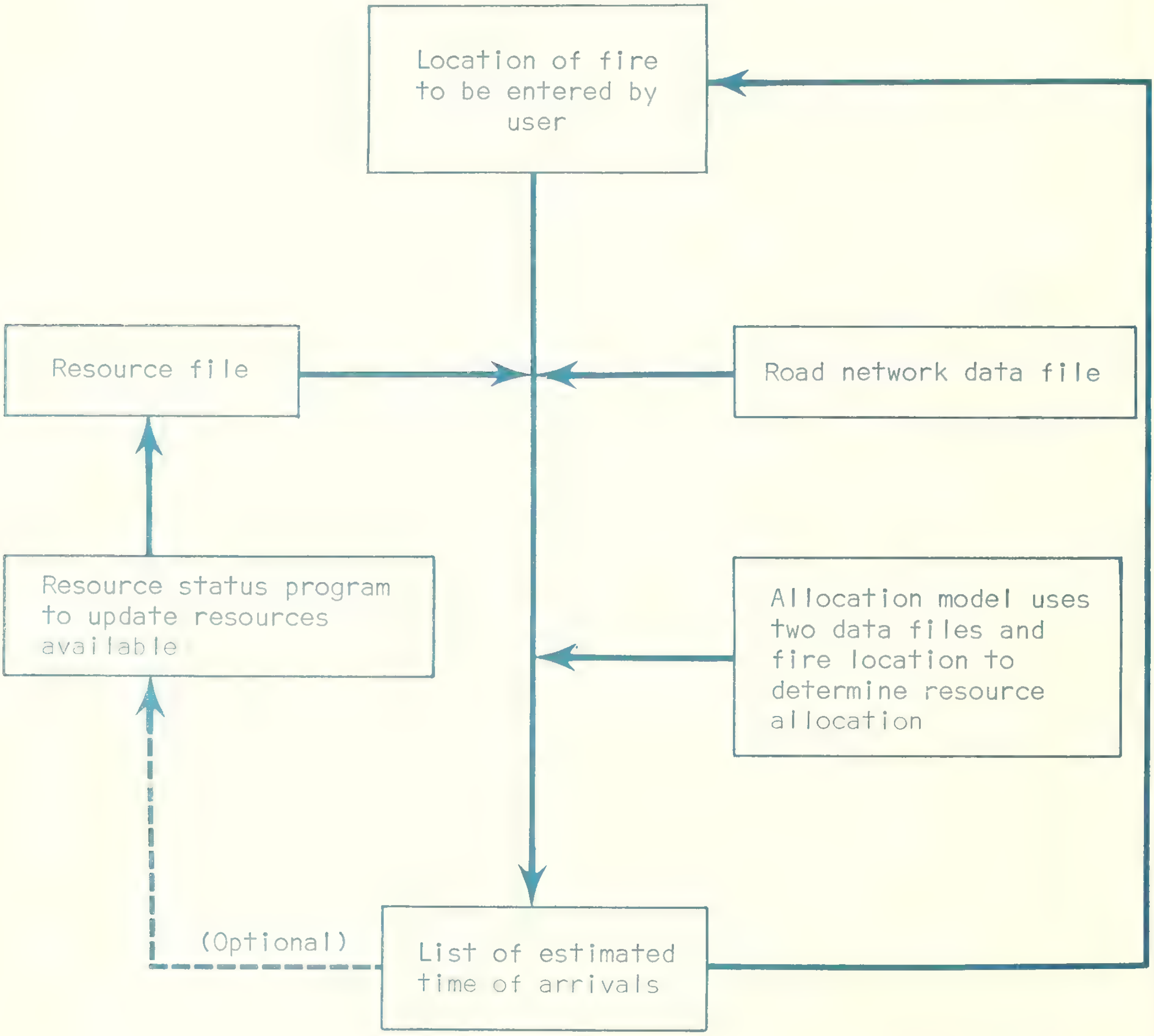
Location of fire to be entered by user
Resource file
Road network data file
Resource status program to update resources available
Allocation model uses two data files and fire location to determine resource allocation
(Optional)
List of estimated time of arrivals

Figure 1—A computer program provides for allocation of resources to a fire followed by a possible update of the resources.

and air units. The total cost (not including monthly storage charges for the required data files) to produce the three samples shown in *tables 1* and *2* was $5.75. The cost to compute initial attack calculations will rise rapidly with increased maximum initial attack time and also with the number of nodes used to define the road network.

The allocation and resource status-keeping programs were written in FORTRAN for operation on the General Electric Tymesharing System.[4] Copies of the programs are available upon request from the Director, Pacific Southwest Forest and Range Experiment Station, P.O. Box 245, Berkeley, California 94701, Attention: Statistical Services Group.

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[4] Trade names and commercial enterprises or products are mentioned solely for information. No endorsement by the U.S. Department of Agriculture is implied.

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The Author

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Acknowledgments

I am grateful to Sanford R. Wilbur (Fish and Wildlife Service, U.S. Department of Interior) for sharing with me his knowledge of the current status of the condor population and for providing me with copies of his unpublished reports on the condor. W. Dean Carrier (Forest Service, U.S. Department of Agriculture) and Fred C. Sibley (Peabody Museum of Natural History, Yale University) both of whom were active in earlier phases of the condor recovery effort, also shared their views with me and provided me with copies of their reports and publications. I also thank Dale E. Birkenholz (Illinois State University), Carl B. Koford (University of California, Berkeley), and Mary F. Willson (University of Illinois), and Paul C. Guilkey, Richard L. Hubbard, and Gale L. Wolters (all with the Pacific Southwest Forest and Range Experiment Station) for consultation on administrative and biological phases of the condor problem.

Verner, Jared
1978. **The California condor: status of the recovery effort.** Gen. Tech. Rep. PSW-28, 30 p., illus. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

Disturbance and high mortality related to human activity have apparently caused the decline of the condor population to about 50 birds. Failure to reproduce successfully is now the central problem; inadequate food supply near nest sites, lack of nest sites in new concentration areas, and pesticide accumulation in condor tissues are possible causes. Low reproductive rate hinders the recovery effort. Results of population modeling indicate that a minimum of eight nesting attempts each year is needed to maintain a population of at least 50; field data indicate that an average of only 1.8 young were produced per year from 1966 through 1976. Principal recommendations include analysis of vegetation structure in the condor range by aerial photographic interpretation; attempts to mark condors for life; standardization of counting procedures; and approval and funding of the proposal to rear condors in captivity.

Oxford: 1482. *Gymnogyps californianus.*
Retrieval Terms: California condor, endangered species, survival, natural history, population dynamics, population modeling.

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jared verner

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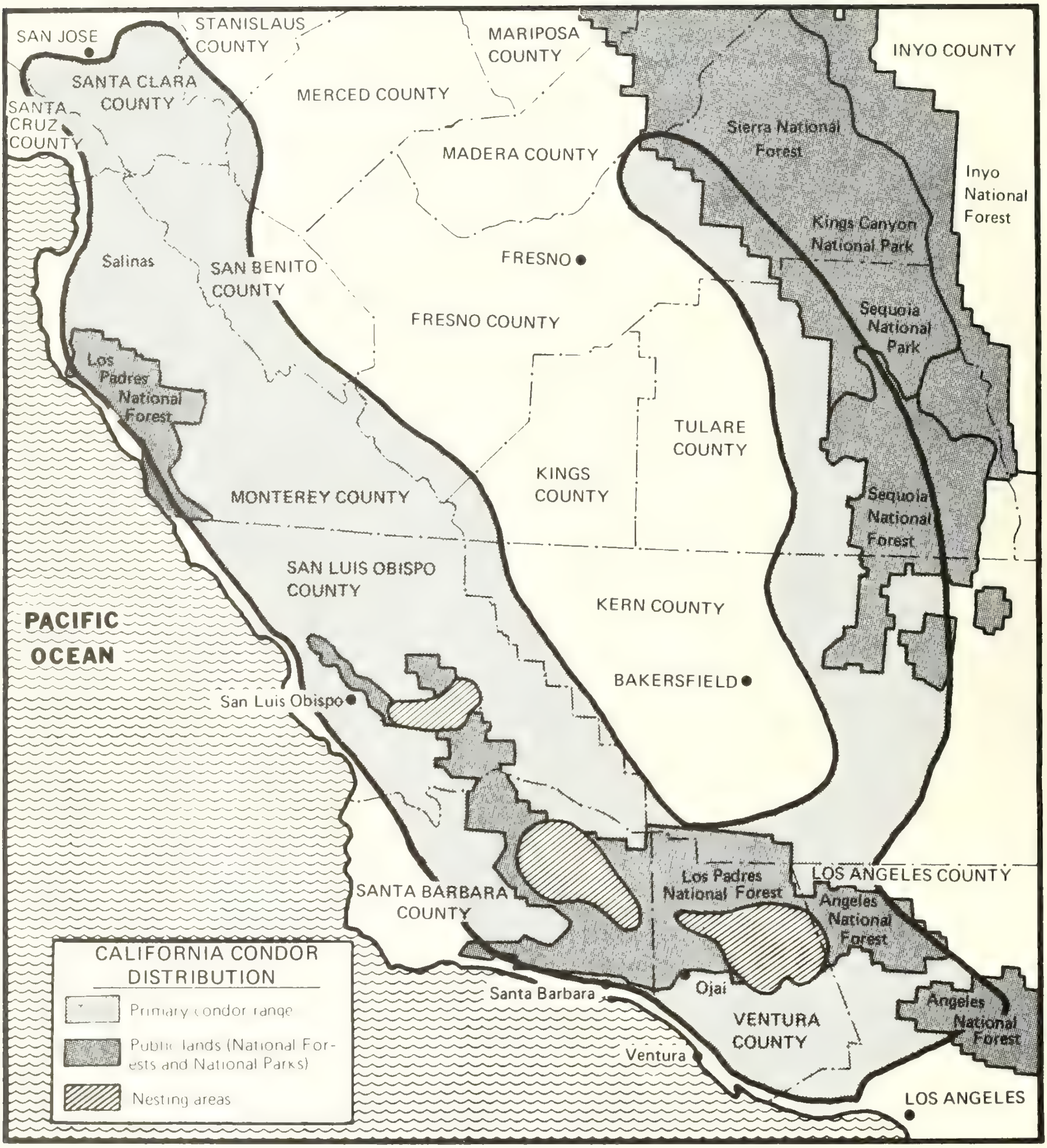
SAN JOSE
STANISLAUS COUNTY
MARIPOSA COUNTY
INYO COUNTY
SANTA CLARA COUNTY
MERCED COUNTY
SANTA CRUZ COUNTY
Sierra National Forest
MADERA COUNTY
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Kings Canyon National Park
Salinas
SAN BENITO COUNTY
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KINGS COUNTY
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BAKERSFIELD
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Angeles National Forest
CALIFORNIA CONDOR DISTRIBUTION
Primary condor range
Public lands (National Forests and National Parks)
Nesting areas
Santa Barbara
Ojai
Angeles National Forest
VENTURA COUNTY
Ventura
LOS ANGELES

In Brief...

In the California condor recovery effort, key life history features pose problems for the population, in its present declining trend. Most important are delayed onset of first reproduction, and low reproductive potential. The condors today are restricted to certain mountainous regions of southern California and are thought by some authorities to be divided into two subpopulations with little or no intermixing of birds. Adults weigh about 9 kg and have a wing span of about 2.9 m. Subadults are distinguishable until about age 5, but only the age class from 3 to 3½ years old can be distinguished with much reliability. First breeding probably occurs no earlier than age 6 and no later than age 10. The single egg typically is laid on the floor of a cliff-face cavity, usually in early March. The young may remain in the nest cave through October, or even later, and the adults may continue to care for their young well into the following spring. No unequivocal data have shown that a given pair breeds more often than every other year, although the possibility of annual breeding may not be ruled out, particularly with ideal conditions.

California condors apparently are carrion feeders exclusively, showing a preference for deer and calf carcasses. Feeding sites must provide ample clearance for landing and takeoff. Condors regularly drink from and bathe in freshwater pools.

Available data show that the population has been declining for the past 125 years, at least, and that probably fewer than 50 birds survive today. Abnormally high mortality, largely attributable to human activities, probably accounted for the decline over most of the specified time period, but today, failure of most condors to breed successfully is the principal reason the population has not stabilized. An annual count of California condors, in October, was initiated in 1965, but it still has not been possible to obtain an accurate estimate of the remaining birds, nor will it be until at least a portion of the population has been individually marked for field recognition. Even trends in the condor population may not be inferred from the annual counts, because counting procedures have not been held constant. Data from high counts of groups of birds, however, suggest about a 30 percent decline in numbers from the early 1940's to the mid-1960's and another 36 percent decline from the mid-60's to December 1976.

Nesting success for the years 1939-41 was about 65 percent; in 1966-68 it was only 45 percent. Since 1969, however, virtually every suspected nesting effort succeeded. Unfortunately, annual production of fledged young has not been sufficient to maintain the population. Never more than three young were produced in any year since 1966; annual average from 1966 through 1976 was only 1.8 young fledged.

Adult sex ratio among living condors is unknown. In museum specimens males outnumber females in a ratio of 60:40.

Results of population modeling indicate that the annual survival rate of adults, throughout the species' history, must have been about 95 percent, and that of subadults (to age 6) about 87 percent, for the condor to have persisted to modern times. These values yield an expected mean longevity of 16.9 years and a maximum longevity of 80 years, beginning with a hypothetical group of 100 dependent young alive in mid-October. If the model assumes a possible bias in the sex ratio of 60 males to 40 females, and a possible long-term average of 75 percent nesting success, a minimum of eight nesting attempts must be made each year to maintain a population of at least 50 condors.

Active efforts to do something about the reduction in abundance and distribution of California condors date from 1939. Most sources of mortality directly attributable to human activities have been eliminated or significantly reduced, as have sources of disturbance at nesting, feeding, and roosting sites. A formal recovery plan has been drafted and approved. A viable public education program is in operation. Supplemental feeding of condors near suitable nest sites has been in effect since 1971. Data have been gathered to suggest that biological concentration of pesticide metabolites may be responsible for recent failure of the condors to breed successfully. And, finally, a formal proposal has been made by the California Condor Recovery Team to erect artificial nest sites in southern Kern County and to begin, as soon as possible, a captive rearing program with the long-term goal of returning reared birds to the wild population.

Major recommendations offered in this report to extend the recovery effort are these: (1) Analyze vegetation structure in the condor range to provide baseline data in the event of significant, future shifts in principal use areas of condors. Similar data from past aerial photography should be sought for comparison. (2) Explore the possibility of individually marking condors for life by use of tattoos. Marked birds are essential if data are to be obtained on movement patterns, absolute population size, age at first reproduction, frequency of breeding by individual birds, and sex ratio. (3) Strive to perfect a method for identification of the sex of captured birds. (4) Employ more seasonal help for field observations, particularly to assist in establishing whether condor breeding efforts fail because of eggshell thinning or because adults fail to initiate nesting activities. (5) Standardize the mid-October counting procedures and rigorously maintain them for an indefinite number of years. (6) Strive to identify the source of any substance toxic to condors by exhaustive assay of all levels in the condor's food web. (7) Approve and fund as soon as possible the Contingency Plan proposal for erection of artificial nest sites. (8) Approve and fund as soon as possible the Contingency Plan proposal to begin rearing condors in captivity, for later release to the wild. If pesticide accumulation is, in fact, the reason for recent failure of condor breeding activity, captive rearing may be the only way to purge birds of their pesticide loads in time to save the population. Captive rearing, if undertaken, should be carried out where birds are to be released, perhaps using a mobile rearing facility.

The California condor (*Gymnogyps californianus*) is among those North American bird species most threatened with extinction. Several agencies (notably the U.S. Fish and Wildlife Service, Forest Service, and Bureau of Land Management; the California Department of Fish and Game; and the National Audubon Society) have invested heavily in resources and personnel in the effort to stabilize the dwindling condor population. Available evidence shows unquestionably that the California condor population has been markedly restricted in distribution and has declined steadily in numbers at least since the early part of the last century. These trends continue today in spite of many programs undertaken to turn the situation around.

Earlier studies identified inordinate mortality as the primary agent in decreasing the number of condors—mortality in large part attributable to human activity (Koford 1953, Miller and others 1965). Steps taken to eliminate most such causes of mortality are realistic and apparently have been largely successful. A secondary factor identified in the condor problem was undue disturbance of the birds by human activities. Disturbances were thought to contribute to abandonment of traditional nesting and roosting areas and even to abandonment of active nests, thus reducing annual production of young condors. Again, measures taken to secure the condors from such disturbances are thought to be adequate and effective (Sanford R. Wilbur, pers. commun.). The decline continues, however, because in recent years few pairs of condors have even attempted to nest.[1] The reasons for this are unknown, although considerable recent evidence points to pesticide accumulation as a causative agent.

This paper first summarizes those life history features germane to population management. Based on this information and on past and present conjecture about population size, some simple models of population dynamics are then presented as a means of improving our ability to determine from censuses any trends in condor population size. An annotated list of the various facets of the recovery effort follows, and, finally, suggestions are made for enlargement of both research and management activities associated with the California condor recovery effort.

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[1] Wilbur, Sanford R. *The California condor, 1966-1974, with a look at its past and future.* (Manuscript in preparation)

Life History

range

The condors today are restricted to a roughly U-shaped range in southern California. The left arm of the U extends northward into the Coast Range Mountains from Santa Barbara to about the boundary between San Luis Obispo and Monterey Counties. From August through December, nonbreeders extend the Coast Range distribution northward to the vicinity of San Jose. The base and right arm of the U extend from the northern fringes of the greater Los Angeles area into the western foothills of the Sierra Nevada Mountains. Yearlong occupancy extends into the Tehachapi Mountains to a point almost as far north as Bakersfield. Nonbreeders range northward in the west Sierran foothills from May through September to about the southern Madera County Line, somewhat northeast of Fresno. Three nesting areas are recognized—the Hi Mountain-Beartrap region east of San Luis Obispo, the Sisquoc area north of Santa Barbara, and the Sespe-Piru area in east-central Ventura County and adjacent Los Angeles County. The Sespe-Piru has long been known as the principal nesting area of California condors.

Two features of condor distribution and seasonal movements have potential significance to effective management for recovery of the population. First, condors occupying the Coast Range area may comprise a subpopulation separate from those breeding in the Sespe-Piru and ranging northward along the western foothills of the Sierras (Wilbur[1] and pers. commun., Wilbur and others[2]). The division between these presumed subpopulations apparently straddles the boundary between Santa Barbara and Ventura Counties. No condors have been marked to test the subpopulation hypothesis unequivocally, but no condors have been seen crossing this boundary in either direction, even though trained observers have spent much time at strategic vantage points. Moreover, the relative numbers of birds observed in the two segments of the range do not change seasonally or from year to year.

Second, nonbreeders from the Sespe-Piru and western Sierra region formerly ranged northward from the breeding area during the May-September period, and returned to the Sespe-Piru for the winter and spring. As birds reached breeding age, they remained to nest in the Sespe-Piru. A reduction in available winter food supply in the Sespe-Piru area may have caused some nonbreeders to shift their wintering range to southern Kern County. This region lacks suitable nest sites, however; a fact which suggests certain stimuli necessary to pair formation and nest site selection may be lacking at the critical time.[1]

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[2] Wilbur, Sanford R., W. D. Carrier, B. K. Muldowney, J. C. Borneman, and W. H. Radtkey. 1974. *California condor recovery plan.* (Available on request from Sanford R. Wilbur, Fish and Wildlife Service, 1190 E. Ojai Ave., Ojai, Calif. 93023.)

physical characteristics

Adult condors weigh approximately 9 kg and have a wing span of about 2.9 m. Plumage is black except on the underwing linings and the edges of the upper secondary coverts, where it is white. The head and neck are naked: the skin on the neck area is gray, but on the head it is yellowish-orange, grading into reddish posteriorly. A large ruff occurs where feathering begins on the neck, and a perched bird may use its ruff to protect its retracted, naked neck. No evident sexual dimorphism in size or plumage exists. Five or six years are required for a bird to attain adult plumage (Koford 1953). Wilbur (pers. commun.) observes that birds 5 years old are essentially indistinguishable from adults, and most subadult age classes cannot be identified with certainty. Among subadults, the one age class that can be most reliably distinguished is the so-called "ring-necked" stage of birds from 3 to 3½ years old.

age at first breeding

Because subadult birds have never been observed as members of breeding pairs, Koford (1953) concluded that age at first reproduction in California condors is *at least* 6 years. Wilbur (pers. commun.) believes the age is more likely to be at least 8 years, based on knowledge of the age at first breeding among other large bird species with long prereproductive periods, as well as the fact that a California condor in the National Zoological Park was 12 years old when it laid its first egg (Dixon 1924). At best, then, our estimate of the mean age is only an intelligent guess, and an error in this guess of only 1 year profoundly affects our ability to assess accurately whether or not condor reproduction is sufficient to maintain the population (compare Cole 1954), as will be shown later in this paper. Furthermore, the key element is not the youngest age at which reproduction occurs among the condors, but the average age of the first *successful* reproduction. In most bird species for which an analysis of breeding success in relation to age has been possible, there is significantly lower success in the first breeding effort than in later efforts, as described by Lack (1966). We can reasonably assume that the condors also improve with experience.

nesting habits

Territoriality evidently is not highly developed among California condors. Territorial encounters have been noted only infrequently, even when several nonbreeding birds roosted near active nests (Koford 1953). Active nests have been located within 1.6 km of each other.

Nest site selection may be a prolonged process, lasting weeks or even months (Sibley 1969). "The main physical requirements for a condor nesting site seem to be: location in cavity in rock (or large tree trunk), suitable roosting perches nearby, fairly easy approach from the air, space below for taking off, protection from storms, winds and direct sunshine, space enough to hold two full-grown condors, level soft area where walls are about two feet apart, and perches available for the young bird when it leaves the nest" (Koford 1953). Most nest caves face either northeasterly or southwesterly (Carrier 1971).

Koford's (1953) observations suggest a breeding phenology as follows:

1. Laying of the single egg extends from February 10 to mid-April, and most laying occurs in early March.
2. Incubation requires 42 days (43 according to

Carrier 1971; possibly up to 60 days, as in the Andean condor, *Vultur gryphus,* according to Wilbur, pers. commun.). It is shared by the sexes, and may continue to late May or early June, depending on laying date.

3. Nestlings are fed by both parents, and the young remain in the nest approximately 20 weeks. Young from late-hatched eggs thus may be in the nest through October. (Koford's figure 10, p 87, suggests young in the nest into December).

4. Young leave the nest long before they can fly, finding perching sites on ledges, rock outcrops, or trees near the nest cavity. There they remain to be fed by their parents for about another 10 weeks, while they are unable to fly long distances; they may change perching sites occasionally. (One juvenile was still within 1.6 km of the nest 10 weeks after leaving the nest. It had changed perches several times and at the age of 201 days was still within 300 m of the nest. It could fly only about 100 m at a time, but not without losing altitude. At 47 weeks it could fly and soar reasonably well, as it was identified among other birds at a watering site. The date was March 21 of the spring following the year it hatched.)

The duration of a successful nesting effort by a pair of condors is a negative factor in efforts to effect recovery of the population, with most condor experts in agreement that a given pair could rear, at most, only one young every other year. This conclusion is based on observations of adults continuing to feed young well into their second year, apparently because an effective social hierarchy makes it difficult for very young birds to obtain much food at carcasses where older, more dominant birds are feeding (Koford 1953, Carrier 1971, Wilbur[1] and pers. commun., Wilbur and others[2]). Carrier and Wilbur have also seen adults feeding young of the previous year, at the nest site, well into the spring (Wilbur, pers. commun.).

Annual nesting may occur, however. Finley (1908) states that "Even under favorable circumstances, each pair of condors will raise but one offspring a year." Koford (1953) reported consecutive use of "nest 5" in 1940 and 1941; the circumstances are not clear, however. The young in 1940 was not seen after it left the nest. It may have perished, so that the pair was free to nest again in 1941; a second pair may have used the nest site in 1941; or possibly the same pair successfully reared the 1940 young to independence in time to renest in 1941. Certainly the best evidence for annual nesting is Sibley's (1970) report of a relatively isolated pair of condors at Hi Mountain, San Luis Obispo

County. Four different sites in a small area were used over a 4-year period. Young were reared at least to the flying stage each year. Sibley (pers. commun.) confirmed his interpretation of this observation as follows: "I feel 100 percent confident that the same pair nested four years running and that each year they successfully fledged the young... I have pushed the interpretation that abundant local food ... allowed for a more rapid development of the young bird." Nevertheless, the successful production of young in each of any two consecutive years still remains to be proved for free-living condors.

Whether or not annual breeding is possible for a pair of condors remains a question of obvious significance to any management program for condor recovery. In any event, it is clear that optimum conditions in nesting areas must be maintained *continuously* in view of the protracted period of nest site selection and the extraordinarily long nesting cycle.

food habits

California condors apparently are carrion feeders exclusively. Ninety-five percent of their food is derived from cattle, sheep, ground squirrels, deer, and horses, and they show a clear preference for deer and calves (Koford 1953). Clearance for landing and take-off is important, so preference is shown for carcasses in short vegetation on ridges. Breeding birds return to the vicinity of the nest after foraging, and according to Wilbur,[1] they probably obtain most of their food within 50 km of the nest. Nonbreeders typically roost near carcasses upon which they have been feeding. Atmospheric conditions suitable for soaring generally limit condor foraging activity to warmer periods of the day. Considering travel time to and from roosts or nest sites, some birds may have only 2 or 3 hours a day of actual search time over suitable foraging areas (Koford 1953). Moreover, because soaring condors probably observe one another closely and follow a descending bird to a newly discovered carcass, a declining population may in itself lessen foraging success when carcasses are scarce or widely scattered.

Condors regularly drink from and bathe in fresh-water pools. The importance of suitable pools that provide easy access and takeoff, and situated within convenient distance of foraging areas, was emphasized by Koford (1953) and Carrier (1971). Miller and others (1965) questioned the importance of fresh water because the condor's size and diet make dehydration unlikely. The special importance of water to these carrion feeders, however, may lie in its use for cleansing the feathers.

Population Dynamics

population trends

During the first half of the 1800's, when the nation's westward expansion was beginning, California condors were distributed northward at least to what is now central Washington, and perhaps even into British Columbia (Jewett and others 1953, Wilbur 1973), and as far south as Baja California. The history of the decline in the number of condors and the restriction of their range has been analyzed recently by many authorities (for example, Koford 1953, Miller and others 1965, Carrier 1971, Wilbur 1973, Wilbur[1], and Wilbur and others[2]), all of whom agree at least in that human activities of various sorts have been primarily responsible. All aspects of this problem need not be summarized here; suffice it to say that wanton shooting, egg collecting, specimen collecting for scientific purposes, general disturbance of nesting areas, and possibly inadvertent poisoning through rodent control projects probably were most important in the decline of the condor population from 1850 to 1950.

Koford (1953) was the first to provide an estimate of total condor numbers based on carefully documented counts by competent observers. His field work covered 400 observation days between March 1939 and June 1941; 80 observation days between February and July 1946; and 15 additional observation days up to the time he prepared his manuscript. The procedure gave the total number of birds counted in different areas at the same time and resulted in a high count of 42 birds on March 26, 1941 (22 at Tejon Ranch and 20 in the Sespe area). An alternate procedure of summing high counts from various widely separated areas over longer periods yielded a high of 43 birds in a 10-day period. Because not all birds would be accounted for by these procedures, Koford increased his counts by about 50 percent, for a final estimate of 60 birds as the total condor population in 1941. No empirical basis was established for the 50 percent added; the value apparently was only an informed judgment.

The next effort to estimate condor numbers was that of Miller and others (1965), based on extensive field work by the McMillan brothers from February 1963 into the summer of 1964. The means of population estimation in that report was comparable to Koford's and yielded high counts of 22 birds at Simi Valley in mid-April 1963, 24 birds at Tejon Flats on October 26, 1963, and 22 birds near Apache Potrero on August 23, 1964. Using data of this sort, in combination with adjustments for adults known to be

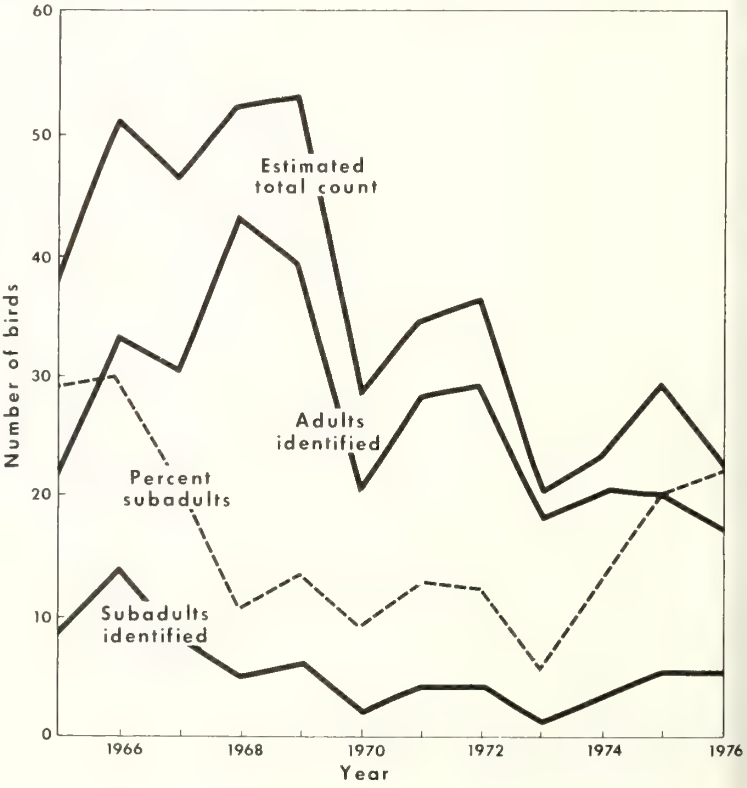


Figure 1—Results of annual condor census (1965-76) show sharp declines in numbers in 1970 and 1973, but these are probably due to procedural changes in the census (see text). For years when counts were made on two or more days, the values were taken from the day with the highest count in each category. The estimated total count includes birds not seen well enough to permit age determination; counts for adults and subadults include only individuals specifically identified as to age class. Percent of subadults = subadults identified / adults identified + subadults identified.

omitted because they were near nest sites, and adding 50 percent to compensate for other birds not in count areas, Miller and his coworkers reached a total population estimate of 42 birds for 1964. This represents a decline of about 30 percent in 23 years.

As a direct result of the study by Miller and others (1965) a condor census was established in mid-October 1965 and has been repeated annually since then. Trained observers at strategic locations, using standard forms, report as fully as possible on the age, activity, and direction of travel of each condor observed. Data from all observation stations are collated in an effort to eliminate duplication in sightings of birds. Details of census conditions (*table 1*) and count estimates (*fig. 1*) were taken from Mallette and Borneman (1966), Mallette and others (1967, 1970, 1972, 1973), Sibley and others (1968, 1969), Carrier and others (1972), and Wilbur (pers. commun.).

Unfortunately, the census procedures originally established in 1965 have not been maintained, so trends in condor numbers (*fig. 1*) cannot be taken as real indicators of population changes. For example, the numbers of observers and observation stations have never been the same in any 2 years of the census (*table 1*). In 1970 the number of stations was reduced by about 78 percent by eliminating all stations with a record of few or no sightings in previous years. The estimated total count of condors (total sightings minus probable duplications, as determined by collating records from different stations) in 1970 was down 66 percent from the year before (*fig. 1*). The number of counting stations was reduced again in 1973, by about 80 percent, and carcasses were placed at the remaining stations to attract more birds to them. The estimated total count in 1973 dropped about 44 percent from the previous year. Indeed, estimated total counts over the years are significantly correlated with the number of counting stations (Spearman's rank order correlation: $r_s = 0.81$, $P<0.01$).

Thus, results of the annual condor census are of no value in determing whether or not the condor population has responded in any way to management activities to date. The census could be useful, however, if procedures were standardized and maintained for several years. At least trends in numbers of subadult and adult age classes could be investigated without biases introduced by procedural changes. Such trends ought to be as reliable indicators of population changes as the high single and high cumulative counts now used as evidence.

The method by which count data should be translated into an estimate of the total condor population for any given year, and the reliability of the estimate, have been much in question. The key to this issue lies in establishing an index for estimating what proportion of the total population is likely to be missed by a given census technique. Obviously no such index is available, nor is it reasonable to assume one may be established in the near future, unless at least a portion of the population is permanently marked for individual recognition.

The magnitude of the decline in the condor population since 1940, when Koford (1953) did most of his field work, has been debated because condor biologists now believe that Koford underestimated the size of the population in 1940-41 and that Miller

Table 1—*Conditions of annual condor census, initiated in 1965*

Date of census (October)		Number of observers[1]	Number of stations[1]	Number of stations reporting birds[1]	Observing conditions
Year	*Day*				
1965	16, 17	98, 91	69, 61	16, 16	Good
1966	18, 19	133, 133	65, 65	15, 23	Good
1967	17, 18	130, 130	69, 69	19, 21	Good
1968	16, 17	137, 136	66, 66	18, 20	Good
1969	15	94,	51	27	Good
1970	21, 22	45, 43	16, 16	11, 8	Fair to poor
1971	13, 14	45, 45	18, 18		Good to poor
1972	11, 12	50, 50	20, 20		Good to fair
1973	2, 3	9, 9	4, 4	4, 3	Good
1973	25, 26	11, 10	5, 5	4, 3	Good to fair
1974	16, 17	25, 25	9, 9	7, 8	Good
1975	21	80	41	16	Good
1976	13, 14	36, 36	12, 12	9, 11	Good

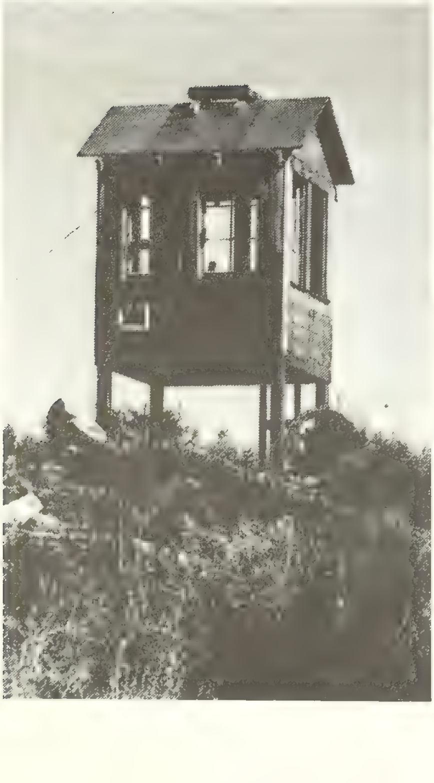
[1] Separate totals are given for each day of the census.

and others (1965) underestimated the 1963-65 population. Details of the basis for this debate are provided in Sibley and others[3] and Wilbur.[1] Biologists Sibley, Carrier, Borneman, and Wilbur all have had access to a growing file of condor sighting cards, which includes cards for all sightings in Koford's original field notes. Thorough study of these records, combined with comparisons of high single counts, data on numbers of known nestings per year, and the assumption that the coastal birds comprise a separate subpopulation, all point compellingly to the conclusion that the condor population in 1940 probably consisted of at least 100 birds (Sibley and others,[3] Wilbur,[1] Wilbur and others[2]). Data gathered by Miller and others (1965) indicate a population decline by that time of about 30 percent (that is, about 70 birds remaining). More recently, authorities (Sibley and others,[3] Carrier 1971, Wilbur,[1] Wilbur and others[2]) interpret censuses and yearlong sightings, carefully studied, to indicate a population of about 50 birds. That number was reaffirmed by Wilbur (pers. commum.) in December 1975 but was revised to about 45 birds in December 1976. In any event, there is little question that the population has declined since Koford's (1953) studies made in the early 1940's.

An indication of population vitality more important than total population size is annual reproduction, which is well summarized by Wilbur.[1] From nest site visitation from 1966-69 and nesting area observations since 1969, annual production of fledged young (1966-76) has been estimated for the coastal subpopulation and the Sespe subpopulation, as follows (Wilbur, pers. commun.):

Year:	*Coast*	*Sespe*
1966	1	2
1967	1 (2?)	2
1968	1	1
1969	1	1
1970	0	2
1971	0	2
1972	1	1
1973	0	0
1974	0	1
1975	0	1
1976	1	1

The decline indicated is supported by estimates of subadult birds in the total population, estimated for the 7 years from 1968 to 1974 as 10,10,13, 8, 8, 6, and 4. The indicated decrease of 60 percent among the subadult population is far larger than the decline likely among adults during the same period (in an estimated total population in 1968 of 61, with 51 adults, and in 1975 of 50, with 46 adults, the decline among adults was only 10 percent).



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[3] **Sibley, Fred C., W. Dean Carrier, and John C. Borneman.** ***Population decline of the California condor.*** **(Manuscript in preparation.)**

The condor population in 1946 was estimated to include from 15 to 20 subadults (Koford 1953), or 25 to 33 percent of the estimated total population. Thirteen nesting attempts (nine succeeded) were documented by Koford over the years 1939-41 and 1946, and he suggested that the population in the early 1940's included 20 adult pairs, 10 breeding per year, with perhaps as many as 5 young surviving each year. Miller and others (1965) estimated that subadults comprised almost 33 percent of the condor population; their study did not include searching for active nests. Their estimates of annual productivity were based on sightings of presumed yearlings; however, according to Sibley (1968), new knowledge of the molt pattern of condors suggests that the estimates may have included some older birds among the counts of yearlings. Wilbur[1] concluded from analysis of the study by Miller and others that no valid comparisons are possible beyond the probability that about 2.5 young were fledged annually in the mid-sixties and that at least seven pairs were reproductively active (not all in the same year). In summary, it seems safe to conclude that data on breeding activity and population age structure point to declining production of young condors. Indeed, if the above estimates of annual production are close, then low reproductive performance by the population as a whole was a significant factor in the population's decline as far back as the 1940's. As will be noted later, in the section Population Modeling, about five or six fledglings must be alive in October to maintain a population of 50 condors.

A weak point in determination of the population's reproductive performance each year is the method of establishing the number of breeding attempts. In a spring visit to canyons containing historic nesting sites, the presence of paired birds is noted, but without follow-up to determine whether or not the birds are actually using one of the sites. The canyons are visited again, late in the fall usually, to search for dependent young. This procedure is followed in part for want of enough personnel to spend the time watching nest sites, and in part to reduce the risk that human interference will cause loss of egg or young or cause the adults to desert the nest. Unfortunately, however, the procedure does not determine when, in the normal breeding cycle, failure occurs, so there is no way to evaluate properly the possible role of pesticides in lowering breeding success. It seems to me that a cautious observer, stationed with a spotting scope on a canyon rim a considerable distance from potential nest sites, could learn whether or not condors were using any of those sites, without unduly disturbing the birds.

nesting success

Information on nesting success for the years 1939-41 and 1966-68 has been summarized by Sibley (1968), based on Koford (1953) and Sibley's own field work. Of 11 known nesting attempts during the 1939-41 period, 7 (65 percent) succeeded, but only 12 of 22 (45 percent) succeeded in 1966-68. Causes of nest failure varied, but disturbance of adults at the nest has been conceded to be important. Of 10 known nest failures, 7 showed egg loss, and 3 showed loss of young. Wilbur[1] (and pers. commun.) has found that since 1969 virtually every suspected nesting effort succeeded. Few useful conclusions can be extracted from these data, except that nesting success can be very high among condors if optimum conditions are maintained, particularly seclusion from disturbance near the nest site, and suitable food sources within easy flight distance of the nest.

sex ratio

Population sex ratio is unknown, as the sexes are not distinguishable in the field and no one has captured the birds for close, on-site examination and release. Sex ratio among museum specimens in adult plumage is approximately 60:40 in favor of males (Koford 1953; Wilbur,[1] and pers. commun.). Although there is no way to determine whether or not this is a fair indication of sex ratio among breeding adults, the possibility exists that among birds of breeding age males outnumber females. Males may be more likely than females to be collected, however, perhaps because they are more likely to approach humans or because they spend less time in parental care (Koford, pers. commun.). A 60:40 sex ratio among adult condors could mean as few as 17 or 18 females of breeding age and only 8 or 9 breeding efforts per year.

Population Modeling

Modeling hypothetical condor populations can provide information useful for a number of critical management decisions; the validity of the conclusions drawn from such models hinges, of course, on the accuracy of the population data utilized. Koford (1953) modeled population age structure on the assumptions of (1) 95 percent and (2) 90 percent annual survivorship, estimating (1) 24 percent and (2) 40 percent subadults. Mean longevities were (1) 20 years and (2) 10 years. These values were translated into numbers based on population estimates of 59 in 1946 and 41 in 1964 (Miller and others 1965), but no significant conclusion emerged.

A more thorough and sophisticated approach to mathematical modeling of the California condor population by Mertz (1971) led to conclusions that may have important management implications:

1. Renesting the year following nest failure has only a slight positive effect on potential for population growth, as expected in a species with long maturation time and low reproductive rate (compare Cole 1954, Lewontin 1965).
2. In a declining population, a shorter maturation time accelerates the rate of decline.
3. In a growing population, a shorter maturation time accelerates growth, but only slightly.
4. The effect of senescence is small unless adult survival rate is high and the postreproductive period is short. The first condition is essential for the condor; the second, though not determined, is unlikely.
5. A change in adult survival rate has a significantly greater effect on population growth potential than a comparable change in subadult survival rate.
6. "Despite the uncertainties associated with the evolution of low reproductive rates, a few requisites are apparent. One is the requirement for a very stable environment–stable in the subjective sense that it must be remarkably free from factors which could cause catastrophic decimation of population numbers. Condors simply do not have the capacity to recoup their numbers quickly following a population crash. For the same reasons, condors would seem to require reasonably permanent geographic ranges; they are incapable of rapidly filling an environment after colonization. Another requirement necessitated by low reproduction is a remarkable freedom from ongoing forms of mortality."

Most points covered in item 6 are obvious, and condor biologists have long been aware of them. But points 1 to 5 are not so obvious and may be vital to effective management of the condor population.

Mertz' paper is less useful than it might have been

if data now available on such matters as numbers, breeding activity, and age structure had been available to him. For example, Mertz reasoned—I believe correctly—that adult survival rate must exceed that of subadults. With this assumption, his calculations showed that "the California condor population cannot withstand an annual adult survival which averages less than about 78 percent. If 50 percent is adopted as a reasonable value for preadult survival, then annual adult survival must average at least 86 percent. In fact, adult survival may have to be much higher than these values, considering that the basic condor life history assumes maximum reproduction." The last sentence holds the key, because at least in recent years the condor population has not demonstrated maximum reproduction, that is, each adult pair breeding every other year. The studies by Sibley, Carrier, and especially Wilbur, as cited earlier in this report, convince me that the condors have not approached maximum reproduction for many years.

replacement reproductive rate

Recruitment into a breeding population must at least equal annual losses if the population is not to decline. On this basis, I have modeled several hypothetical condor populations to estimate (1) the numbers of dependent young (nestlings or fledglings) that must be alive each October to maintain the population, (2) the expected proportions of recognizable subadults among volant birds, (3) the effect of separate subpopulations on maintenance-level reproduction, and (4) the impacts on maintenance-level reproduction resulting from changes in survival rates among subadults as opposed to those among adults. The modeled populations were fitted to an October-to-October cycle because that cycle coincides with the period of the annual condor census, and because the absolute number of dependent young birds alive in October probably can be assessed more accurately than the absolute number of any other age class.

The estimate of 50 condors (Wilbur,[1] and pers. commun.) was used to derive age structures of three hypothetical populations. Available data on annual reproduction led me to doubt whether there is more than one surviving bird in each prereproductive age class. Accordingly, on the assumptions of prereproductive periods of 6, 8, and 10 years, models have been designed for stable populations of 44 adults and 6 subadults, 42 adults and 8 subadults, and 40 adults and 10 subadults. Five different rates of mean annual survival (91, 93, 95, 97, and 99 percent) were selected and modeled for adult birds. The real adult survival rate probably lies within this range (Koford

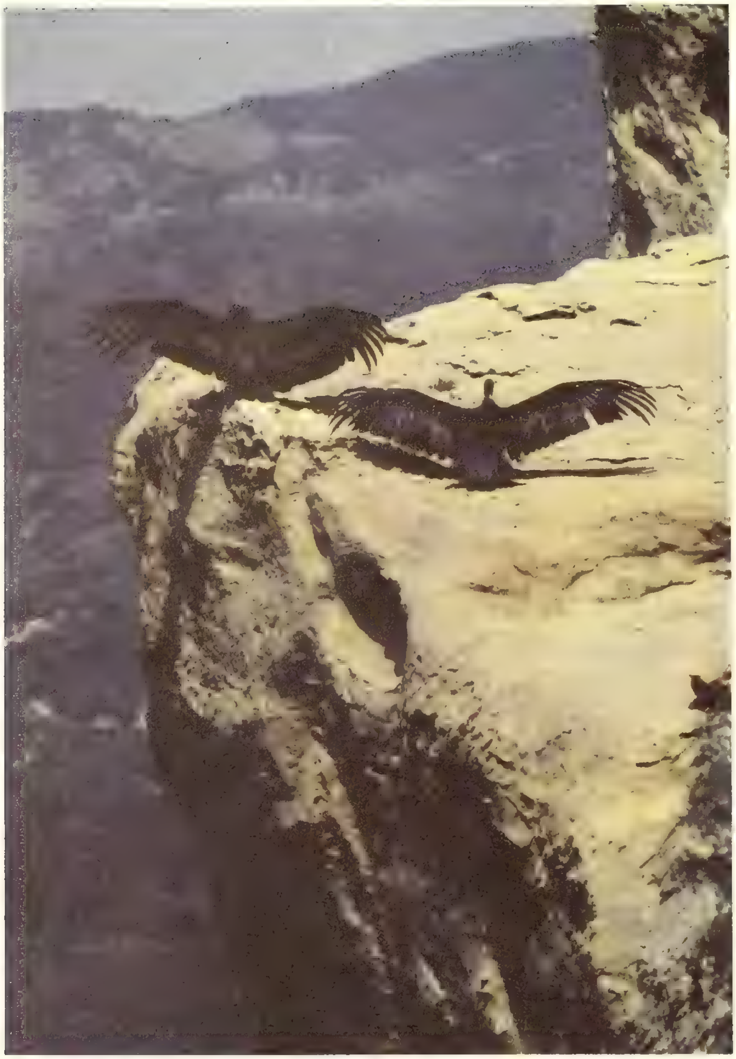

Table 2–*Mean annual losses among adult condors, as a function of adults in population and annual survival rate.*

Adult population	Annual losses of adults at annual adult survival rate of . . . 91 pct.	93 pct.	95 pct.	97 pct.	99 pct.
	Single, panmictic population				
40	3.60	2.80	2.00	1.20	0.40
42	3.78	2.94	2.10	1.26	.42
44	3.96	3.08	2.20	1.32	.44
	Two subpopulations				
8	.72	.56	.40	.24	.08
34	3.06	2.38	1.70	1.02	.34

1953, Mertz 1971, and Wilbur[1]). The expected numbers of annual losses from the breeding population for the various models are shown in *table 2.*

Three possible survival rate schedules of subadults were examined in the models. These were selected to provide increasing survival rate with increasing age, leading to mean annual survival rates of subadults, from age 0.5 to 6.5 years, of approximately 85, 87 and 89 percent (*table 3*). Note that even with an average annual survival rate of 89 percent, fewer than half of the dependent young alive in October would be expected to live to 6.5 years of age. Birds older than 6.5 years were assumed to survive at the same rate as adult birds for each population modeled. Values in *tables 2* and *3* were used to calculate the minimum numbers of dependent young that must be alive in October to maintain condor populations with different numbers of adults and various subadult and adult survival rates (*tables 4 and 5*).

A primary goal of the California Condor Recovery Team is to maintain the condor population at 50 birds, with annual reproduction at 4 (Wilbur and others[2]). The modeling (*tables 4* and *5*) suggests that this rate of reproduction will suffice only if the adult survival rate approaches 97 percent per year. As discussed below, I believe 97 percent to be possible, but suspect that a value of 95 percent is more likely as a long-term average.

Table 3–*Annual (October to October) condor survival rates selected for various subadult age classes, to lead to all-age mean subadult annual survival rates of approximately 85, 87, and 89 percent*

Item	Survival rates to yield all-age mean of . . . 85 pct.	87 pct.	89 pct.
		Percent	
Age class, years:			
0.5 to 1.5	80	82	84
1.5 to 2.5	82	84	87
2.5 to 3.5	84	86	90
3.5 to 4.5	86	88	91
4.5 to 5.5	88	91	91
5.5 to 6.5	90	91	91
Percent of original population of dependent young alive at age 6.5	37.5	43.2	49.6

Table 4–*Numbers of dependent young needed in mid-October to maintain a population of 50 condors as a function of adult and subadult survival rates and age at first reproduction.*

Adult (A) and and subadult (S) survival rates (percent)		Dependent young needed if age at first reproduction is . . . 6 years (44 adults)	8 years (42 adults)	10 years (40 adults)
A = 91	S = 85	10.55	12.16	13.99
	S = 87	9.17	10.57	12.16
	S = 89	7.99	9.21	10.59
A = 93	S = 85	8.21	9.06	9.98
	S = 87	7.13	7.87	8.67
	S = 89	6.21	6.86	7.55
A = 95	S = 85	5.86	6.20	6.54
	S = 87	5.10	5.39	5.69
	S = 89	4.44	4.69	4.95
A = 97	S = 85	3.52	3.57	3.61
	S = 87	3.06	3.10	3.14
	S = 89	2.66	2.70	2.73
A = 99	S = 85	1.17	1.14	1.11
	S = 87	1.02	.99	.96
	S = 89	.89	.86	.84

Needed reproduction based on two subpopulations is compared in *table 5* with that based on a single, panmictic population. Minimum essential reproductive output, for all condors collectively, differs according to the survival rate combinations. Eight of the fifteen combinations require more total young if the subpopulation theory is correct, and these include most of the survival rate combinations that I believe are realistic for California condors. The difference exists because at these mean survival rates, fractions of condors are calculated to disappear from the population each year, but replacement figures must show the next whole number above any given fraction. The actual minimum essential reproduction thus hinges on whether or not the subpopulation theory is valid.

The fact that death of fractions of condors requires whole-number replacements, in the simplistic models developed here, has another implication for population management. The survival rates modeled are inconsistent with a stable condor population of 50 birds. If too few offspring are produced, the

Table 5—*Number of dependent young needed in mid-October to maintain two condor subpopulations, totalling 50 birds, as a function of adult and subadult survival rates*[1]

Adult (A) and subadult (S) survival rates (percent)		Dependent young needed for two subpopulations		Dependent young needed, in whole numbers	
		8 adults	34 adults	Two subpopulations	One population
A = 91	S = 85	2.32	9.87	13	13
	S = 87	2.01	8.56	12	11
	S = 89	1.75	7.46	10	10
A = 93	S = 85	1.73	7.33	10	10
	S = 87	1.50	6.46	9	8
	S = 89	1.31	5.55	8	7
A = 95	S = 85	1.18	5.02	8	7
	S = 87	1.03	4.36	7	6
	S = 89	.89	3.80	5	5
A = 97	S = 85	.68	2.89	4	4
	S = 87	.59	2.51	4	4
	S = 89	.51	2.19	4	3
A = 99	S = 85	.22	.92	2	2
	S = 87	.19	.80	2	1
	S = 89	.16	.70	2	1

[1] Age at first reproduction is assumed to be 8 years; a total of 42 adults is assumed.

population obviously declines; production of enough to compensate for annual losses, on the other hand, will be too many for all survival rate combinations except those calling for 99 percent annual survivorship among adults. There, stable populations of fewer than 50 birds could result, but at every other percentage the population would increase to some number less than 100 birds before it stabilized (*fig. 2*). Thus if condor reproduction can be increased enough to compensate for annual losses, we should actually expect to observe a slow increase in numbers until a balance is reached between whole-number loss and whole-number replacement.

Differences in subadult survival rate have little effect on stable population size (*fig. 2*). Indeed, minimum numbers of dependent young needed in mid-October to maintain the condor population (*table 4*) increase an average of 4.83 with a decline in adult survival rate from 97 to 93 percent, over the range of subadult survival rates from 85 to 89 percent. A comparable decline in subadult survival rate, from 89 to 85 percent over the range of adult survival rates from 93 to 97 percent, requires an average increase of only 1.52 dependent young needed in mid-October. Of course the important implication of this result is that loss of an adult condor from the population is about three times more detrimental than the loss of a subadult.

The frequencies of immature age groups in the

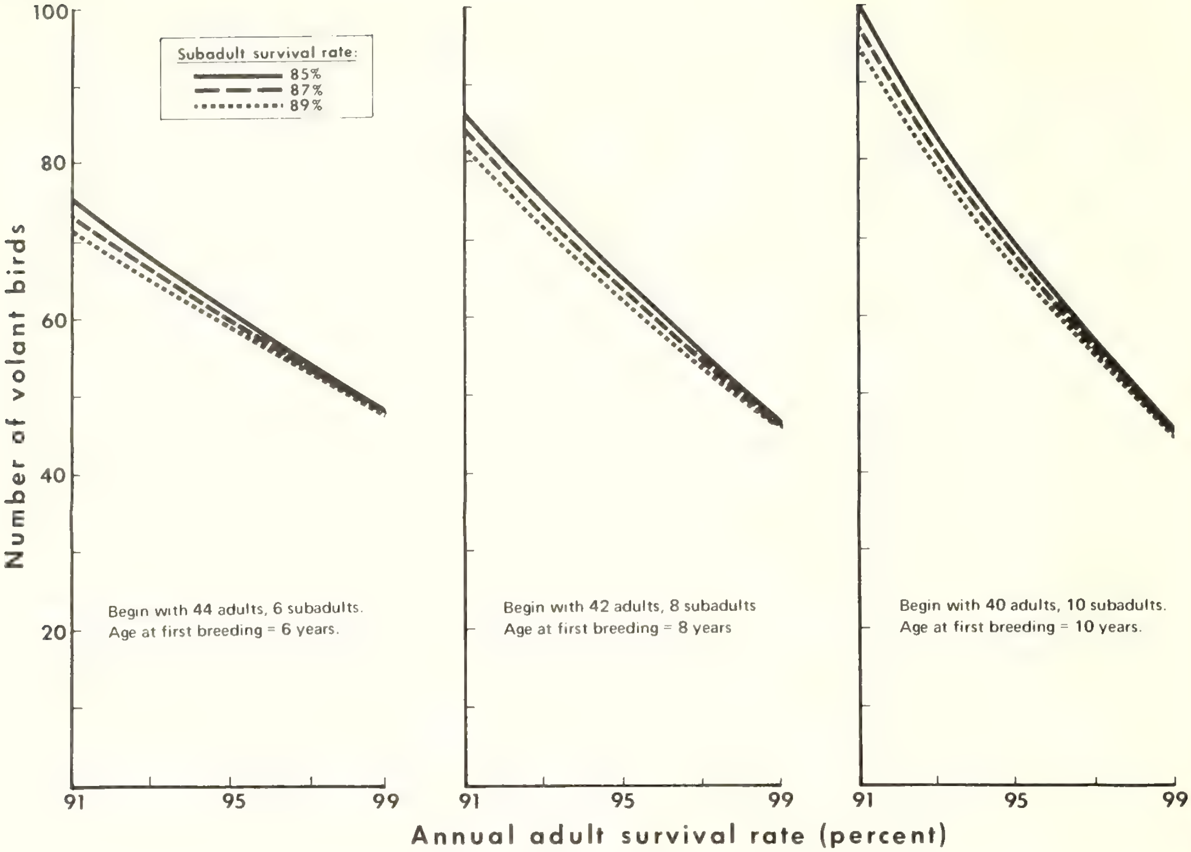

Figure 2—The number of volant birds in a stable population of the California condor is shown as a function of the assumed survival rates of subadults and adults. Curves are shown for three assumptions of the proportion of subadults to adults and the age at first breeding for initial populations of 50 birds.

population might be indicative of trends in population size, as suggested by Koford (1953) and Mallette and others (1970). Mertz (1971) affirmed this but cautioned that "for age distribution to be very informative, we should need some estimate of the prereproductive survivorship curves for successful condor populations." My modeling indicates that application of age distribution data in condor management depends even more on knowledge of adult survival rate than it does on knowledge of subadult survival rate. The percent of recognizable subadults (age classes 1.5, 2.5, 3.5, and 4.5 years) in a *stable* condor population declines sharply with increasing adult survival rate (*fig. 3*), dropping from about 33 to 36 percent subadults to about 5 to 7 percent subadults as adult survival rate climbs from 91 to 99 percent. Varying the subadult survival rates affects the expected percentages of recognizable subadults so minimally as to be immeasurable with the imprecise censusing techniques available for condors (*fig. 3*). Even knowledge of the percentage in the total population of the 3.5-year age class, the one most easily distinguished, is of little value without knowledge of adult survival rate

Unless more is known about trends in the various age classes, knowledge of age ratios is of practically no value in assessing the vitality of a population. The modeling done here is for stable populations. If both age groups (subadults and adults) were declining at the same rate, the same age ratios as expected in a stable population would apply; so also if both age groups were increasing at the same rate. On the other hand, if the adult segment were declining at a faster rate than the subadult segment, there would be an increasing trend in the ratio of subadults to adults, and this might be interpreted as a healthy sign for the population.

In the absence of solid data on total numbers of

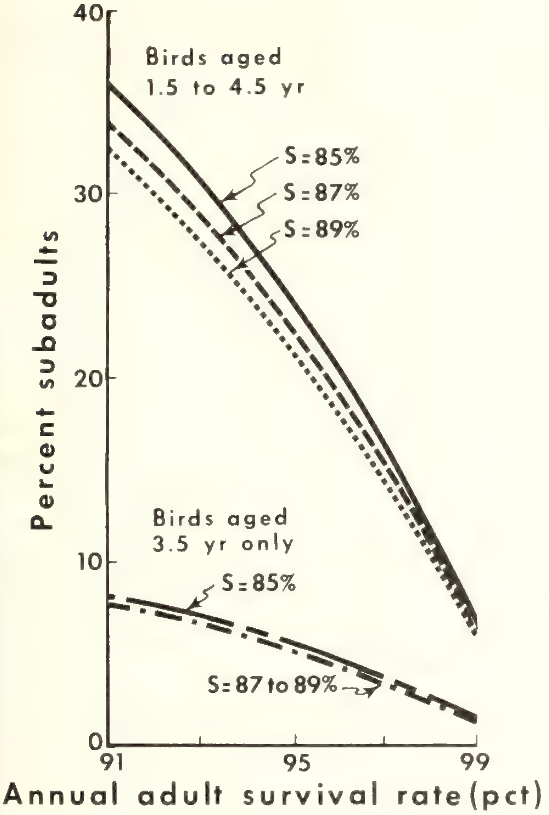

Figure 3—The proportion of subadults to adults among volant birds in stable California condor populations in October is shown as a function of adult and subadult survival rates.

birds in each age group, the best approach still seems to be to compare, from year to year, such data as high counts for a single day and total numbers of sightings in different areas over longer time periods. This is the approach that has led current condor biologists to conclude that the population today is probably less than half the size it was in 1940 and perhaps only two-thirds the size it was in 1965.

Figure 3 may be used to obtain a better estimate of real adult survival rate among California condors. Earlier estimates of the percentage of immatures in the condor population range from 25 to 33 percent (Koford 1953, Miller and others 1965). These estimates correspond to a stable population with adult survival rates from 92 to 94 percent (*fig. 3*). Even during the early period of the annual condor census, subadults comprised nearly 30 percent of the confirmed sightings (*fig. 1*). If these percentages accurately reflect condor population age structure in past years, then the population should have increased if adult survivorship were even as high as 95 percent. Because all indications are that the population has declined, it seems safe to conclude that adult survival rate, at least over the period 1940-70, averaged less than 94 percent.

survivorship

Hypothetical survivorship curves may be constructed from assumed subadult and adult survival rates, as Koford (1953) did. The models used here start with 100 dependent young alive in October and project numbers of survivors in subsequent Octobers; so results may have more direct application to the annual condor census. Curves thus generated (*fig. 4*) provide information about mean and maximum longevity (*table 6*), and about the percentages of subadult age classes in the volant population (*fig. 3*). Expected percentages of different age classes in an October population, as calculated from survivorship curves, did not differ from comparable estimates derived from modeling for replacement production.

Data on mean longevity of condors fortify earlier statements about minimum possible combinations of subadult and adult survival rates. Note, for example, that adult/subadult survival rates of 91/85 percent, 91/87 percent, and 91/89 percent yield mean longevities so low (*table 6*) that an average pair would not survive long enough to rear two young, given the widely accepted assumption that it normally takes 2 years to rear a young to independence. This limita-

Table 6—*Mean and maximum longevity as a function of adult and subadult condor survival rates, modeled from initial populations of 100 dependent young alive in October*

Adult (A) and subadult (S) survival rates (percent)		Longevity	
		Mean	Maximum
		Years	
A = 91	S = 85	9.2	45
	S = 87	9.6	46
	S = 89	9.9	48
A = 93	S = 85	11.6	56
	S = 87	12.1	58
	S = 89	12.5	60
A = 95	S = 85	16.3	77
	S = 87	16.9	80
	S = 89	17.4	83
A = 97	S = 85	27.6	126
	S = 87	28.4	130
	S = 89	29.1	135
A = 99	S = 85	86.7	367
	S = 87	88.3	381
	S = 89	89.7	395

tion holds regardless of whether reproduction begins at 6, 8, or 10 years of age. Even assuming 1.5 years to be the usual time required to rear a condor to independence, first breeding at age 8, and mean longevity of 15.5 years, the average pair of condors could attempt to breed only four times before dying. With 75 percent success in rearing young to independence, the pair would produce three offspring; an incredible 97.4 percent mean annual survival rate would be necessary if these birds were to reach mean longevity of 15.5 years. Thus longevity among California condors probably evolved to be in excess of 15.5 years, indicating an adult survival rate of about 95 percent. Only with successful breeding beginning at age 6, and/or with annual reproduction an occasional or regular event, might these estimates be appreciably lower.

This question is explored in greater depth in *table 7*. Obviously, the values shown must exceed 100 percent if the population is to survive, given the assumptions specified. It is easy to identify those combinations of survival rates, sex ratio, and age at first breeding that are possible with biennial reproduction. Given a reasonable expectation of no more than 75 percent nesting success, an adult survival rate of 91 percent is impossible for all conditions except a 50:50 sex ratio, first breeding at age 6, and annual subadult survivorship of at least 89 percent. The assumptions of a 60:40 sex ratio and first breeding at age 8 require an adult survival rate of 95 percent for all three subadult survival rates tested. Identical conclusions result from comparing minimum numbers of dependent young required to maintain various adult populations (*table 4*). In summary, both modeling approaches attempted here suggest that minimum feasible rates for long term survival of California condors probably have averaged about 95 percent among adults and about 85 to 87 percent among subadults.

Thus if the population were stable today we should observe from 22 to 24 percent subadults in the volant population (*fig. 3*). This proportion has not been observed in recent years, probably because reproductive output by the population has declined. And as most data point compellingly to a decline in the number of adults as well, the prospect is even

Table 7—*Attainable percentage of the minimum number of breeding pairs required to maintain the condor population, as a function of adult and subadult survival rates, sex ratio, and age at first reproduction*[1]

Adult (A) and subadult (S) survival rates (percent)		Percentage of minimum by age at first reproduction and sex ratio					
		6 years		8 years		10 years	
		50m:50f	60m:40f	50m:50f	60m:40f	50m:50f	60m:40f
A = 91	S = 85	109	87	90	72	74	59
	S = 87	123	99	102	81	84	67
	S = 89	142	114	117	94	97	77
A = 93	S = 85	136	109	117	93	101	80
	S = 87	157	125	135	108	116	93
	S = 89	180	144	155	124	134	107
A = 95	S = 85	190	152	169	135	152	122
	S = 87	217	174	195	156	176	141
	S = 89	250	200	225	180	203	162
A = 97	S = 85	310	248	291	233	273	219
	S = 87	358	286	336	268	315	252
	S = 89	412	329	387	309	363	291
A = 99	S = 85	919	735	899	720	881	705
	S = 87	1060	848	1038	831	1017	814
	S = 89	1221	977	1196	957	1172	937

[1] Table values assume biennial reproduction, so would be doubled if pairs reproduced annually. Values also assume that all breeding-age pairs breed and that all successfully rear one young at least to October. Any value greater than 100 percent indicates a possible combination of survival rates, sex ratio, and age at first reproduction. With 75 percent nesting success, any value less than 133 indicates an impossible combination.

more grim than trends in age ratios might lead us to conclude.

Maximum longevity is difficult to determine from simple assumptions about adult and subadult survival rates, because estimated maximum longevity increases with the size of the original cohort of dependent young selected for modeling. Prolonged prereproductive life and the limit of 1 offspring per breeding effort suggest that the peak of reproductive value in condors coincides with mean age at first successful reproduction (compare Fisher 1958, and Wilson and Bossert 1971). This conclusion, together with theoretical development of the probable mode of evolution of senility (Williams 1957, Medawar 1957, and Hamilton 1966), leads me to suspect that the California condor is subject to senescent death, in the sense of increasing likelihood of organic failure with advancing age. Mertz (1971) concluded, from an analysis of the impact on population growth of senescent failure to breed, that condors likely evolved to maintain reproductive vigor "well past half of a century." I agree and would not be surprised if some individuals survive 75 years, a figure consistent with conclusions about probable minimum survival rates (see above). This age may not be out of line with a maximum age of perhaps 45 years reached by a captive bird,[1] since conditions of captivity may well have been conducive to early death. If very old birds (whatever that may mean) decline in reproductive vigor or are subject to senescent death, this would have the effect of reducing slightly the estimates of mean longevity as calculated from hypothetical survivorship curves. The magnitude of such an effect, however, probably would not substantially alter conclusions reached here about minimum, essential reproduction; because postreproductive birds (if present at all) should comprise a negligible percentage of the total population (*fig. 4*).

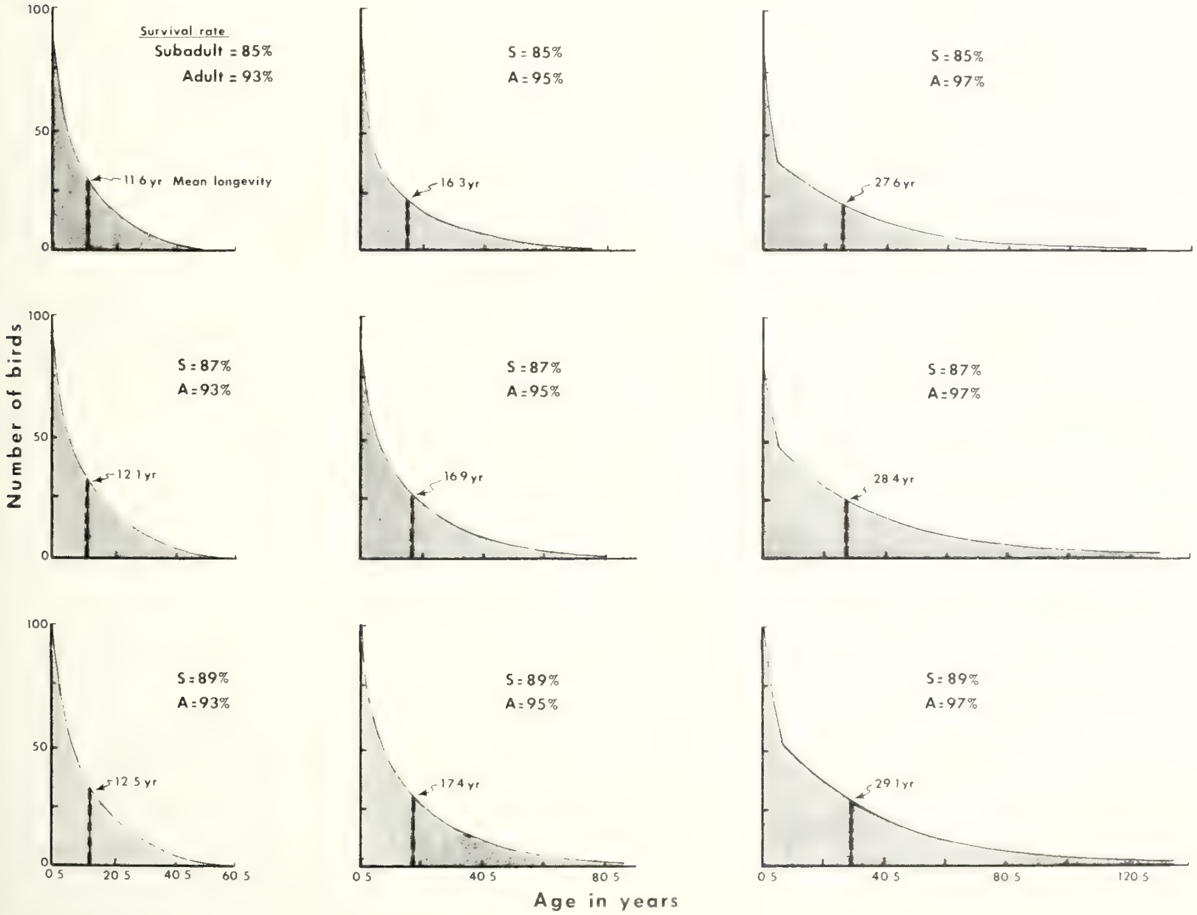

Figure 4—Survivorship curves of beginning populations in October of 100 dependent young are plotted here under varying assumptions of survival rate. (The subadult survival rate applies for the first 6 years.) Mean longevity is shown for each curve.

Current Status of the Condor Recovery Effort

Koford (1953) presents a concise chronicle of the shrinking range of California condors in the western United States, dating from about 1840. The record is, of course, scanty. But it is clear. Even though the decrease in abundance and distribution of condors was well known for nearly a century, no serious effort was undertaken to study the birds until Koford initiated his research in 1939. That work brought focus on the critical status of the condor population. Even beyond that, however, Koford's (1953) monograph on California condors is an early landmark in the development of public awareness of extinction as a fact of life during modern times, an awareness tangibly expressed in the passage by Congress, in 1973, of the Endangered Species Act.

The key developments in the condor recovery effort have implications which require discussion; these implications lead to specific recommendations made in the final section of this report.

1. The studies of Koford (1953) and Miller and others (1965) developed the factual basis for measures to protect condors from unnecessary, human-related mortality. Establishment of condor sanctuaries in the Sisquoc and Sespe-Piru areas followed. These studies also suggested the need to identify causes of disturbance of condors at their feeding sites, their roosting sites, and, especially, their breeding sites. Sibley (1969) investigated this problem and was able to specify minimum tolerable distances from sites of condor activity for disturbances.

2. The Endangered Species Act (1973) requires that a recovery team be established to draft a recovery plan for every endangered species in the United States. The California Condor Recovery Team was among the first of these teams to be established, its members representing the U.S. Fish and Wildlife Service, the U.S. Forest Service, the California Department of Fish and Game, the National Audubon Society, and the U.S. Bureau of Land Management. This team prepared a recovery plan (Wilbur and others[2]), which spells out those actions deemed most vital at this time to success of the condor recovery effort. In the plan, time schedules, responsible organizations, and cost estimates are itemized for 12 land acquisition actions, 6 investigative actions, and 21 administrative actions. Land acquisitions, protective patrols, mining and oil search closures, and closure of air space to 3000 feet above condor habitat are designed to provide maximum security of the birds from disturbance. Some objectives appear well on the

way to being achieved at this time. Other actions, proposed or ongoing, are discussed below.

3. Education of the public about all aspects of the condor problem, and particularly about condor identification, is recognized as highly important in the recovery effort. The National Audubon Society has assumed major responsibility for this task and has assigned to it a fulltime condor biologist, John C. Borneman. The education program is being pursued with vigor and success (Wilbur, pers. commun.).

4. A possible reason so few pairs of condors, in recent years, have begun breeding efforts is a lack of adequate food resources sufficiently near nesting sites to permit efficient parental foraging for a growing young (Sibley 1968, Wilbur 1972). It is difficult to document such a deficiency. No hard data are available, for example, on the mean distance from the nest that breeding birds ordinarily forage. Such information must be obtained by following marked birds.

The most thorough and most recent appraisal of food resources is that of Wilbur (1972), Wilbur[1] and Wilbur and others.[2] Wilbur finds reason to believe that "food in the vicinity of the Sespe-Piru nesting areas may be inadequate to release the reproductive function in some condors. Observations of feeding condors indicate there is a well-defined 'peck-order,' with certain individuals and pairs dominating carcasses to the almost complete exclusion of others."

A pilot project (Wilbur and others 1974) to assess the impact of supplemental feeding on breeding activity in the Sespe-Piru area began in February 1971. Results, though not conclusive, suggested that continuation of the program was warranted. Goats, road-killed deer, and other large animal carcasses are collected and frozen until needed. These are then placed within 3 to 6.5 km of known nesting sites. Different carcasses are placed far apart in an effort to assure ready access to food by subordinate condors otherwise excluded by the social hierarchy. This program is in operation over as much of the year as possible, but to date it has not been linked to any marked increase in numbers of condor pairs breeding in a given year.

5. Food supply problems motivated Cowles' (1958) suggestion that effective fire prevention, by allowing secondary succession, may make some areas unsuitable for foraging; under these conditions habitats might support fewer deer, or meadows might grow up to dense shrub cover not allowing ready landing and takeoff. Miller and others (1965) were critical of Cowles' idea because it came at a time when deer numbers were high, and it tended to paint an unwarranted picture of starving condors. In a later paper, Cowles (1968) pressed the issue again, making

the provocative point that condor food habits necessarily may have changed in recent years because shrub closure of traditional feeding sites may have forced the birds into extensively grazed lands where most of their food today consists of large animal carcasses. Perhaps carcasses of small animals, such as rabbits and squirrels, comprised an important part of the condor diet prior to effective fire suppression. Such animals are small enough that some of their bones would be ingested by the condors, providing a source of calcium for eggshell production. Bones of larger animals could not, of course, be ingested.

In any case, Cowles has focused attention on a major void in the condor recovery effort. No quantitative baseline studies have been made of the character of the vegetation in areas frequented by California condors today, nor do we have any information on vegetation structure in prior decades.

6. Biological concentration of toxic substances is another suspected agent in low reproductive performance of the condors. An immature condor that died accidentally in May 1965 had concentrations of 18 ppm p,p^{1}DDT and 20 ppm p,p^{1}DDE in its visceral fat (Hunt 1969). Another, found dead in November, 1974, had 50 ppm p,p′DDE and much smaller concentrations of other organochlorines in muscle tissue from the leg.[4] An adult female died at the Los Angeles Zoo on October 30, 1976, after being discovered in an emaciated condition 2 weeks earlier. The bird had been shot in the wing. Tissue analyses by California Department of Fish and Game showed 14 ppm p,p′DDE in fatty tissue, and another sample of the same tissue was found by the Patuxent Wildlife Research Center to contain 105 ppm p,p′ DDE (Wilbur, pers. commun.). The basis for this discrepancy is presently unresolved, but even the lower level of DDE in the bird is a matter of concern.

DDT metabolites may affect an organism's steroid hormone balance so as to interfere with normal reproductive behavior (Henkin and others 1971, p. 99-103, provide a succinct summary of this point; see also Stickel 1975). Evidence suggests that Andean condors in Peru concentrate chlorinated hydrocarbons to much higher levels than other local bird species high on their respective food chains (D. W. Anderson, pers. commun. cited by Wilbur[1]). It is entirely possible that high concentrations of pesticide metabolites in California condors have so interfered with hormone balance that birds cannot begin breeding activity.

A better known role of DDT metabolites in avian physiology is in eggshell thinning. Garrett and others[5] recently found that California condor eggshell fragments taken from nests during 1965-69 were 31 percent thinner than shells of eggs collected from 1806 to 1943. Structural abnormalities were also apparent in the shell fragments from the 1960's. Scanty though the data are, they nonetheless indicate that pesticide contamination is a likely factor in low condor reproductive output.

Wilbur (pers. commun.) reported that a number of research projects are now, or soon will be addressed to this problem. Among them are these:

A comparative chemical analysis of condor feathers taken from museum specimens collected be-

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[4] Patuxent Wildlife Research Center, Laurel, Md. (Report on file, cited by Wilbur.[1])

[5] Garrett, R. L., L. F. Kiff, and S. R. Wilbur. *Recent changes in California condor eggshell thickness and structure.* (Manuscript in preparation.)

fore widespread use of pesticides, and from feathers found recently.

Comparative chemical analyses of old fecal samples (obtained from deposits in nest cavities) and fresh ones.

Continued analyses of the possible negative impact of toxic substance accumulation on breeding of turkey vultures.

Continuing efforts to identify all possible sources of toxic substances in the food web exploited by California condors.

7. Investigations are in progress to perfect identification of the sex of condors through chemical analyses of fecal samples and other means (Wilbur, pers. commun.).

8. Evidence that part of the population from the Sespe-Piru area may have relocated in southern Kern County, where there are few suitable nest sites, suggests that artificial nest sites there may stimulate nesting. A proposal for such a project was presented to the California Condor Advisory Committee on May 20, 1976.[6] It has been approved at all levels within the U.S. Fish and Wildlife Service and is now under study by the Office of Endangered Species in Washington, D.C. (Wilbur, pers. commun.).

9. Artificial propagation has been conceded by most of those closest to the condor recovery effort to be a "last resort" operation, but at a meeting (May 20, 1976) with the California Condor Advisory Committee, the California Condor Recovery Team proposed such a program.[6] This proposal also has been approved at all levels within the Fish and Wildlife Service and is now under study by the Office of Endangered Species in Washington (Wilbur, pers. commun.).

10.The U.S. Fish and Wildlife Service (1976) began a captive rearing program with Andean condors at the Patuxent Wildlife Research Center, Laurel, Maryland, in 1966. Immature birds taken from the Andes in 1966 and 1967 were paired off and the pairs placed in separate pens in 1971. Since that time, 3 pairs have laid a total of 10 eggs. Six hatched, and 4 young have survived. A pair of Andean condors at the San Diego Zoo produced 9 young in 11 years, from 1942 to 1952, because either the egg or the young was taken from the pair early enough to free them for reproduction the following year (Lint 1959). The same pair in the wild should have produced only about 5 young in the same period.

Two captive female California condors in the National Zoological Park laid a total of 19 eggs from 1919 to 1939, all infertile because no males were available (Wilbur, pers. commun.).

These experiences with captive condors have provided valuable information applicable to a similar program with California condors. For example, we know that appropriate timing in removing young birds from the care of their parents promises to double a pair's reproductive potential. Personnel are available with considerable experience in handling Andean condors and limited experience in handling California condors. And pen conditions conducive to pair formation and breeding by Andean condors are known, a factor which should reduce the time needed to find suitable pen conditions for California condors.

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[6] California Condor Recovery Team. 1976. *Contingency plan.*

Recommendations

These recommendations imply a basic assumption that all efforts made thus far to ensure recovery of the California condor population should continue until there is clear evidence that discontinuing a given effort will not jeopardize the prospects of recovery. Any possible deterrent to condor survival and reproduction must be considered, and every reasonable effort at mitigation must be made. We can hope, then, that only "safe" errors would be made—that is, some insignificant problems would receive attention but no significant ones would be ignored.

1. *Analyze vegetation structure in areas now frequented by the condor.* The analysis may be used for comparison in the event of significant relocations in zones of principal condor activity. Data probably can be obtained satisfactorily by aerial photography, that is, from the condor's view. Information about vegetation structure in the condor's range in past decades should be sought and compared with today's pattern.

2. *Explore effects of two kinds of marking programs, on a pilot basis.* Many questions vital to wise management of the condors cannot be answered without detailed knowledge of such things as age, sex, local and long-distance movement patterns, and frequency of breeding by individual birds. Marking for individual recognition should thus have high priority, but only on a pilot basis initially, to determine whether or not the marking procedures negatively affect the welfare of marked birds.

One marking program should utilize the most up-to-date radio transmitter technology possible. At least one and perhaps two birds (one from each presumed subpopulation) should be fitted with transmitters for the pilot study.

A second program should have the ultimate aim of marking for life as many California condors as possible, so that the mark is unique and identifiable from some distance. Because the traditional means of permanently marking birds would not be suitable, use of tattoos should be explored. A two-letter code in black, tattooed on the back of each condor's head in a size legible for some distance with aid of a spotting scope, would suffice to mark 676 individuals. Marking should include nestlings and subadults, even though their marks would not be visible until their head color changed from black to the yellowish-orange characteristic of adults.

The process might best be tested first on turkey vultures, and perhaps on Topatopa, the captive California condor in the Los Angeles Zoo. It should then be field tested on one or two condors to determine whether or not the markings affect them negatively.

3. *Strive to perfect a method for identification of the sex of captured birds.* Sex determination is a necessary component of the long-term marking program, although many vital data could be obtained through marking without sex identification.

4. *Employ more seasonal help for field observations.* Some assistants could work on regular checking of potential nesting areas to establish whether condor breeding efforts fail because of eggshell thinning or because the adults never begin nesting activities.

In a marking program, other temporary aides could be stationed in blinds near animal carcasses to record markings on condors attracted to the carcasses. These observers could also record other information and test various methods of possible value in condor management. For example, they could note age and sex differences in feeding success at carcasses, and could assess the value of positioning multiple carcasses in increasing feeding success of subordinate birds. They could test other means for individual recognition of condors (perhaps footprints), and evaluate the possibility of obtaining repeated weights of known individuals by placing scale platforms on perches near the carcasses.

5. *Standardize the mid-October census procedures and rigorously maintain them for an indefinite number of years.* If it is combined with a systematic, individual marking program and extensive observation of birds at carcasses, from blinds, a standardized census in mid-October should permit determination of the total condor population, with little error.

6. *Strive to identify the source of any substance toxic to condors.* First, a systematic program of testing air samples from various points in the condor range should be started. Second, a comprehensive trace element assay should be directed at all levels in the condor's food web. Simultaneously, those species whose feeding ecology is most like that of the condors should be similarly tested, especially ravens (*Corvus corax*), coyotes (*Canis latrans*), and black bears (*Ursus americanus*).

7. *Increase the California Condor Recovery Team's goal of four condor offspring per year to at least six.* If six offspring are to be produced each year, management probably should aim toward about eight nesting attempts per year.

8. *Approve and fund as soon as possible the Contingency Plan proposal*[6] *for erection of artificial nest sites.* Sites should be located in appropriate habitat in southern Kern County, and perhaps in other parts of the condor range. Artificially excavated caves on cliff faces would be preferred, but, where necessary, artificial cliffs could be constructed. They should be

designed so that if condors ever used them for nesting, an observer's station could be added within the "cliff" to permit direct study of parent-offspring relationships at the nest.

9. *Explore the use of condor models in various postures.* Models may be valuable in conjunction with artificial propagation as a stimulant to reproduction by captive pairs, and they might prove useful in directing attention of free-living condors to artificial nest sites.

10. *Approve and fund as soon as possible the Contingency Plan proposal*[6] *to begin rearing condors in captivity, for later release to the wild,* There is, of course, no guarantee that captive rearing would succeed, so any decisions on this vital issue must be adequately based on public understanding and support. I am cautiously optimistic, however, that such a program would be successful. We have the experience of the captive rearing of Andean condors to draw upon. The program has the potential of doubling the reproductive potential of captive pairs. The birds are scavengers; they need not learn to locate, attack, and kill moving prey. Thus they should be more easily naturalized than predatory birds from a captive to a free-living existence.

Recent evidence of the likelihood of pesticide accumulation as a factor in low reproduction makes captive rearing even more appropriate. Captive birds could be placed on a diet known to be free of toxic substances, and the birds' present loads of such substances should be more rapidly purged from their bodies, permitting them to begin breeding successfully sooner than they would in the wild. Finally, if pesticide interference with sex hormone balance is a problem, captive rearing at least offers a chance to restore the natural balance by artificial administration of sex hormones.

If the captive rearing project is approved, the following additional recommendations should be considered:

A. *Rear captive birds in areas where they will be released,* at least from the time they are taken from their parents. It would be advisable to rear them in simulated nest cavities, as studies of other species indicate that breeding locality is markedly influenced by rearing locality.

B. *Use a rearing facility that could be moved from one area to another;* relocation would be determined by the optimum number of birds to be released in each area.

C. *Carefully study the optimum number of birds to be released in any given area.* Population modeling discussed in this report suggests that addition of just a single bird to a small subpopulation may have a major impact on its reproductive potential.

D. *Carefully consider the optimum age for release of birds,* again including population modeling studies. Some compromise may be necessary, since older releases probably would have a higher survival rate, but they also may be more likely to maintain some level of dependence upon or contact with humans.

E. *Evaluate proposed rearing and release sites for air pollution and food chain contamination.*

F. *Permanently mark all captive-reared birds,* as with tattoos, to permit adequate documentation of the success or failure of the project.

Literature Cited

Carrier, W. Dean.

1971. **Habitat management plan for the California condor.** Admin. Rep., Los Padres National Forest, U.S. Forest Service, U.S. Dep. Agric., 54 p.

Carrier, W. Dean, Robert D. Mallette, Sanford Wilbur, and John C. Borneman.

1972. **California condor survey, 1971.** Calif. Fish and Game 58:327-328.

Cole, Lamont C.

1954. **The population consequences of life history phenomena.** Quart. Rev. Biol. 29:103-137.

Cowles, Raymond B.

1958. **Starving the condors?** Calif. Fish and Game 44:175-181.

Cowles, Raymond B.

1968. **Fire suppression, faunal changes and condor diets.** Proc. Calif. Tall Timbers Fire Ecology Conf., Nov. 9-10, 1967. 7:217-224.

Dixon, J.

1924. **California condors breed in captivity.** Condor 26:192.

Finley, William L.

1908. **Life history of the California condor.** Part II. Historical data and range of the condor. Condor 10:5-10.

Fisher, Ronald A.

1958. **The genetical theory of natural selection.** 291 p. Dover Publications, New York.

Hamilton, W. D.

1966. **The moulding of senescence by natural selection.** J. Theoretical Biol. 12:12-45.

Henkin, Harmon, Martin Merta, and James Staples.

1971. **The environment, the establishment, and the law.** 223 p. Houghton Mifflin Co., Boston.

Hunt, E. G.

1969. **Pesticide residues in fish and wildlife of California.** *In* Peregrine falcon populations, their biology and decline. J. J. Hickey, ed. p. 455-460. Univ. Wisc. Press, Madison.

Jewett, Stanley G., Walter P. Taylor, William T. Shaw, and John W. Aldrich.

1953. **Birds of Washington State.** 767 p. Univ. Washington Press, Seattle.

Koford, Carl B.

1953. **The California condor.** National Audubon Society Res. Report 4. 154 p. [Reprinted 1966, Dover Public., New York.]

Lack, David.

1966. **Population studies of birds.** 341 p. Clarendon Press, Oxford.

Lewontin, Richard D.

1965. **Selection for colonizing ability.** *In* The genetics of colonizing species. H. G. Baker and G. L. Stebbins, ed. p. 77-94. Academic Press, New York.

Lint, Kenton C.

1959. **San Diego's Andean condors . . . A closeup of one of the world's most incredible birds.** Zoonooz 32:3-7.

Mallette, Robert D., and John C. Borneman.

1966. **First cooperative survey of the California condor.** Calif. Fish and Game 52:185-203.

Mallette, Robert D., John C. Borneman, Fred C. Sibley, and Raymond S. Dalen.

1967. **Second cooperative survey of the California condor.** Calif. Fish and Game 53:132-145.

Mallette, Robert D., Fred C. Sibley, W. Dean Carrier, and John C. Borneman.

1970. **California condor surveys, 1969.** Calif. Fish and Game 56:199-202.

Mallette, Robert D., Sanford Wilbur, W. Dean Carrier, and John C. Borneman.

1972. **California condor survey, 1970.** Calif. Fish and Game 58:67-68.

Mallette, Robert D., Sanford R. Wilbur, W. Dean Carrier, and John C. Borneman.

1973. **California condor survey, 1972.** Calif. Fish and Game 59:317-318.

Medawar, P. B.

1957. **The uniqueness of the individual.** 191 p. Methuen, London.

Mertz, David B.

1971. **The mathematical demography of the California condor population.** Amer. Nat. 105:437-453.

Miller, Alden H., Ian I. McMillan, and Eben McMillan.

1965. **The current status and welfare of the California condor.** National Audubon Society Res. Report 6. 61 p.

Sibley, Fred C.

1968. **The life history, ecology and management of the California condor (*Gymnogyps californianus*).** Annual Progress Report, Project No. B-22. U.S. Bur. Sport Fish. and Wildl., Patuxent Wildl. Res. Cent. 34 p.

Sibley, Fred C.

1969. **Effects of the Sespe Creek Project on the California condor.** Admin. Rep., U.S. Bur. Sport Fish. and Wildl., Patuxent Wildl. Res. Cent. 19 p.

Sibley, Fred C.

1970. **Annual nesting of the California condor.** Paper presented at the annual meeting of the Cooper Ornithological Society, Fort Collins, Colorado, June 18-21, 1970.

Sibley, Fred C., Robert D. Mallette, John C. Borneman, and Raymond S. Dalen.

1968. **Third cooperative survey of the California condor.** Calif. Fish and Game 54:297-303.

Sibley, Fred C., Robert D. Mallette, John C. Borneman, and Raymond S. Dalen.

1969. **California condor surveys, 1968.** Calif. Fish and Game 55:298-306.

Stickel, William H.

1975. **Some effects of pollutants in terrestrial ecosystems.** *In* Ecological toxicology research. A. D. McIntyre and C. F. Mills, ed. p. 25-74. Plenum Publ. Co., New York.

U.S. Fish and Wildlife Service

1976. **Second stage of condor breeding program near completion.** Endangered Species Tech. Bull. 1, p. 2, 4.

Wilbur, Sanford R.
1972. **Food resources of the California condor.** Admin. Rep., U.S. Bur. Sport Fish. and Wildl., Patuxent Wildl. Res. Cent. 18 p.

Wilbur, Sanford R.
1973. **The California condor in the Pacific Northwest.** Auk. 90:196-198.

Wilbur, Sanford R., W. Dean Carrier, and John C. Borneman.
1974. **Supplemental feeding program for California condors.** J. Wildl. Manage. 38:343-346.

Wilbur, Sanford R., W. Dean Carrier, John C. Borneman, and Robert W. Mallette.
1972. **Distribution and numbers of the California condor, 1966-1971.** Amer. Birds 33:819-823.

Williams, George C.
1957. **Pleiotropy, natural selection, and the evolution of senescence.** Evolution 11:398-411.

Wilson, Edward O. and William H. Bossert.
1971. **A primer of population biology.** 192 p. Sinauer Assoc., Stamford, Conn.

Photograph Credits

The illustrations in this publication were chosen to clarify the description of the California condor – its characteristics, life history, and habitat. Photographs were generously provided by agencies and individuals directly concerned with the condor recovery program, as follows:

Black-and-white photographs (except page 22):
Carl B. Koford, Museum of Zoology, University of California, Berkeley.
Page 22: Fred C. Sibley, Fish and Wildlife Service, U.S. Department of Interior.

Color photographs (centerfold):
Top right: Sanford R. Wilbur, Fish and Wildlife Service.
Center: David J. Dunaway. California Region, Forest Service.
Bottom right: David J. Dunaway, California Region, Forest Service.
Top left and bottom left: Fred C. Sibley, Fish and Wildlife Service.

Coding Hazardous Tree Failures for a Data Management System

Lee A. Paine

CLEMSON UNIVERSITY
SEP 17 197

IFIC SOUTHWEST
rst and Range
priment Station

GENERAL TECHNICAL
REPORT PSW-29

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Stn., Forest Serv., U.S. Dep. Agric . B [illegible]

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failure data submitted on Report of Tree Failure forms. Defi [illegible] ports are also included. The [illegible] ure the production of accurate and consistent punched ADP [illegible] are used in transfer of the data to magnetic tapes. The codes and card [illegible] and analysis programs provided in a user's guide, General Technical Report PSW-24. The guide [illegible] o specify the desired categories and ranges of data (species, diameters, organization, areas, times, conditions, etc.) to be included in analyses.

[illegible] reation areas: url [illegible] safety standards; data management; computer programs; coding.

Lee A. Paine is a forest pathologist, stationed in Berkeley, studying problems in [illegible] oded recre [illegible] the Canadiai [illegible] master's (1947) degrees in forestry from the Univer [illegible]

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[illegible] embodies many suggestions and modifi [illegible] by the originators and users. I am grateful to the forestry, biology and statistical aids, both graduate and undergraduate students at local universities, who have made the coding manual easier to use by discovering inconsistencies and ambiguities. Their work has improved the data coding process and, in the end, the reliability of data analyses. In particular, I thank Richard D. Boothe, who was largely responsible for the forest type code condensation and descriptions.

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1979. Coding hazardous tree failures for a data management system. Gen. Tech. Rep. PSW-29, 108 p., illus. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

ADDENDA

The following items should be inserted in the manual on the indicated pages.

Page 7, just above H. Property or Person Directly Affected, insert:

City parks—Code as site category 1.

Page, 15 after 766 BASSWOOD, WHITE insert:

512	BAY, CALIFORNIA	UMBELLULARIA CALIFORNICA

Page 16, after 767 DOGWOOD, RED-OSIER insert:

728	DOMBEYA	DOMBEYA SPP.

Page 19, after 743 SUMAC, STAGHORN insert:

567	SWEET BAY	LAURUS NOBILIS

Page 21, after 813 SHIN OAK insert:

830	OVERCUP	Q. LYRATA	SE	(W)
830	SWAMP POST	Q. LYRATA	SE	(W)
830	SWAMP WHITE	Q. LYRATA	SE	(W)

Page 21, after 816 WILLOW insert:

830	WATER WHITE	Q. LYRATA	SE	(W)

Page 56, under CORPS OF ENGINEERS, indented under LITTLE ROCK DISTRICT insert:

MILLWOOD RES	42305 01

Page 57, after COE (HENRY W.) ST PARK insert *, and at bottom of page add:

*COLONEL ALLENSWORTH SHP	52530 00

Page 62, after MALIBU CREEK SP insert:

COLONEL ALLENSWORTH SHP	52530 00

Page 64, after ZIBE DIMMICK STATE PARK insert:

TRYON CREEK	52150 00

Page 68, after SPENCER SPIT insert:

SADDLEBAG ISL	52367 00

Page 106, next to number 728 insert:

DOMBEYA	DOMBEYA SPP.

Page 108, next to number 830 insert:

OVERCUP	Q. LYRATA	SE	(W)

Coding Hazardous Tree Failures for a Data Management System

Lee A. Paine

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Pacific Southwest Forest and Range Experiment Station
P.O. Box 245
Berkeley, California 94701
December 1978

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This manual is a tool for establishing files in the data management system for hazard control described in a separate user's guide[1]. Information supplied on the "Report of Tree Failure" *(fig. 1)* must be interpreted and coded so that accurate data processing cards may be produced in a format compatible with the programs used for computer processing and analysis. These programs are available on request, as indicated in the user's guide.

After cards are punched, they are put in sequential order for screening by the ERROR CHECK program (see the user's guide). For most uses, the verified data are then transferred to computer tapes. From these, analyses in tabular form may be obtained through the FAILURE program, or selected cards or limited-data tapes may be re-created from the master tapes. In all phases of the data management system, accurate coding, transcription, and card-punching are essential; errors may interfere with proper operation of the computer programs or produce misleading results in analyses.

GUIDELINES FOR CODING

A first step in preparing for the coding process is to gather together useful references to supplement the coding manual itself. Such references include maps showing county, agency, and city boundaries and recreation site locations; silvics references with species distribution maps; dendrology manuals; check lists for technical nomenclature and for common and local names; references describing the flora of specific areas; and "blue books" with prices of new and used items including automobiles and recreation vehicles.

For automatic data processing (ADP), each valid report of tree failure is first coded on the report form itself, following codes given in this manual. Then the information on the report is punched on ADP cards, as described under "Format for ADP Cards." Codes are needed for most items on the report, and for a few additional items not indicated on the report form itself. Codes for these additional items are determined as explained under "Coding Specific Items."

The report form shown in *figure 1* (modified to include labeled spaces for coding) has the advantage of eliminating a step in preparation of the punched cards—the transcription of codes to a worksheet. A

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[1] Paine, Lee A., and James W. Clarke, 1978. *Tree failures and accidents in recreation areas: A guide to data management for hazard control*. Gen. Tech. Rep. PSW-24, 30 p., illus. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

1/1-5 2/1-5 Number: ______________

1/6 2/6 Card: 1 2

REPORT OF TREE FAILURE ①

(Mechanical break, collapse, or uprooting)

REPORTING AGENCY: ______________________________ UNIT: ______________________________ 1/44-51

(A) Tree and stand

1/7-9 Species: ______________________________

1/11-12 Approximate dbh of tree: ______________ inches

1/14-16 Approximate age of tree: ______________ years

1/18-19 Forest type: ______________________________

1/21 Stand age class:
- ___ Overmature
- ___ Mature
- ___ Young-growth
- ___ All-age

1/23-26 Elevation of site: ____________________ _____

(B) Class of mechanical failure 1/27

- ___ Upper bole (top half)
- ___ Lower bole
- ___ Butt (lower 6 feet)
- ___ Limb
- ___ Root, including uprooting

(C) Tree defect or fault leading to failure ② 1/29-30

1/32-33 1/35-36
- ___ Rot (trunk, limb, or root)
- ___ Sweep
- ___ Tree dead - snag
- ___ Fire wound
- ___ Leaning
- ___ Lightning wound
- ___ Mechanical wound
- ___ Cracks or splits
- ___ Fork or multiple top
- ___ Twin bole or basal fork
- ___ Dead top or branch
- ___ Widow-maker or hang-up
- ___ Canker, rust
- ___ Canker, mistletoe
- ___ Other: ______________________________
- ___ Unknown or none

(D) Contributing factors 1/38

1/40 1/42
- ___ Wind
- ___ Snow
- ___ Erosion
- ___ Soil - saturation
- ___ Stream bank erosion
- ___ Shallow rooting
- ___ Tree striking tree
- ___ Other: ______________
- ___ Unknown or none

(E) Time and location of incident 1/52

Approximate hour: ______________________________ 1/53-54

Month, year: ______________________________ 1/56-59

County: ______________________________ 1/63-65

State: ______________________________ 1/61-62

Site open for public use: Yes ____ No _______ 1/67

(F) Land ownership 1/69

- ___ Federal
- ___ State
- ___ Other public: ______________________
- ___ Private
- ___ Public utility

(G) Site category 1/71

- ___ Established camp or picnic ground
- ___ Other established public use site ③
- ___ Volunteer site ④
- ___ Marked trail
- ___ Special use site ⑤
- ___ Roadside
- ___ Residence site ⑥
- ___ Other: ⑦ ______________________
- ___ Urban

(H) Property or person directly affected 1/73

- ___ Agency
- ___ Recreationist
- ___ Forest industry
- ___ Permittee-Concessionaire
- ___ Other: ______________________
- ___ Contractor
- ___ Public utility

(I) Consequences

- ___ Clean-up work required 1/2/80
- ___ Property damaged: ______________ 1/75, 2/7, 2/9-13
- Property loss estimate: $______________ 2/14-18
- ___ Injuries (Do not give tree values) 1/77, 2/20
- ___ Medical attention required 2/22
- ___ Fatalities 1/79, 2/24

2/44-76 (J) Name of site: ⑧ ______________________________ 2/26

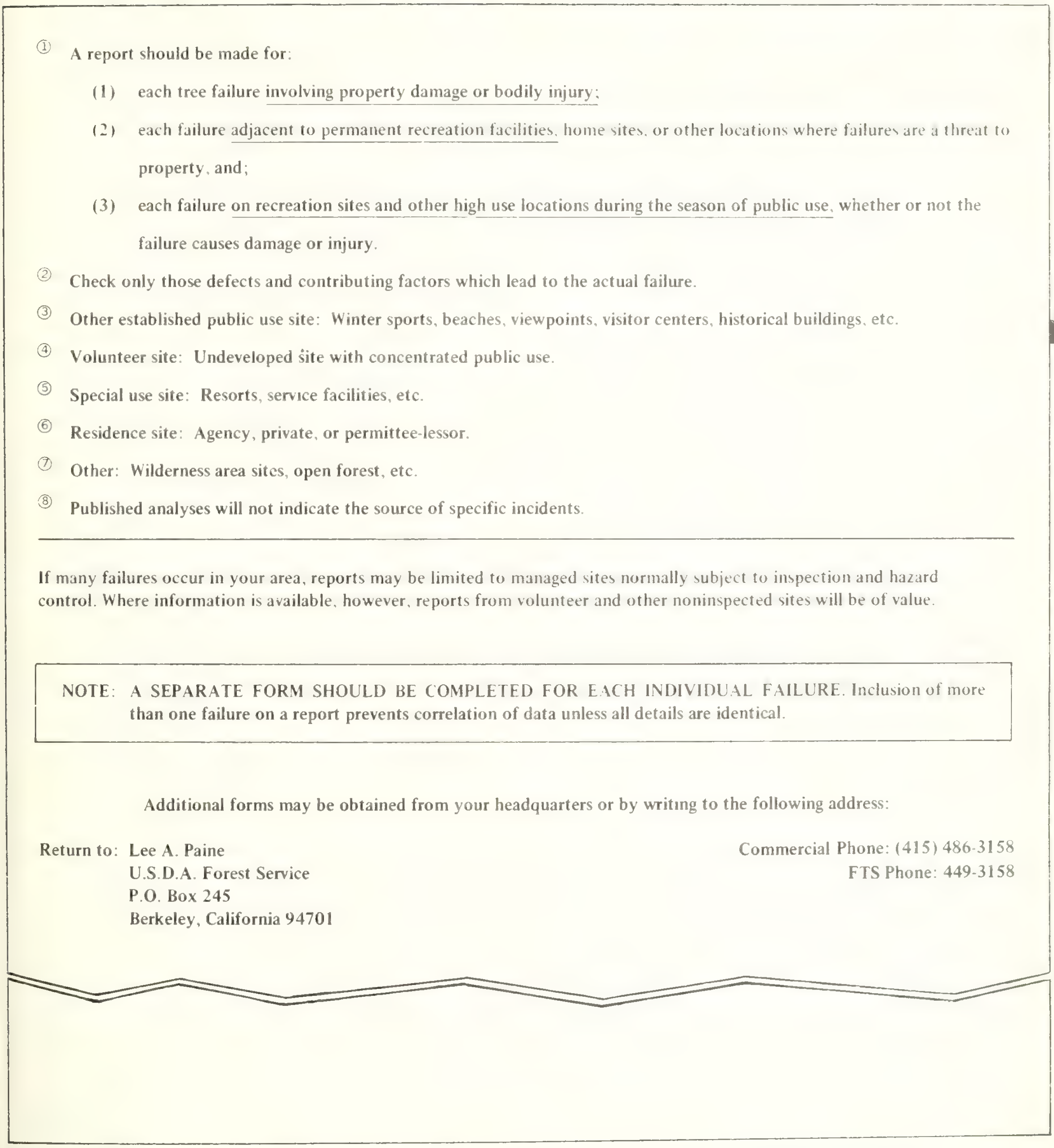
Comments: ______________________________ 2/27-31

______________________________ 2/33-38

______________________________ 2/40-42

Only failures of a size capable of inflicting some damage or injury should be reported. Minor limb failures should not be reported unless they were potentially dangerous. Do not report simple death of a tree or part of a tree unless it resulted in mechanical failure. Trees removed prior to failure should not be reported.

Forest Service Form PSW-4600-3 (Rev 6/75)



① A report should be made for:

(1) each tree failure involving property damage or bodily injury;

(2) each failure adjacent to permanent recreation facilities, home sites, or other locations where failures are a threat to property, and;

(3) each failure on recreation sites and other high use locations during the season of public use, whether or not the failure causes damage or injury.

② Check only those defects and contributing factors which lead to the actual failure.

③ Other established public use site: Winter sports, beaches, viewpoints, visitor centers, historical buildings, etc.

④ Volunteer site: Undeveloped site with concentrated public use.

⑤ Special use site: Resorts, service facilities, etc.

⑥ Residence site: Agency, private, or permittee-lessor.

⑦ Other: Wilderness area sites, open forest, etc.

⑧ Published analyses will not indicate the source of specific incidents.

If many failures occur in your area, reports may be limited to managed sites normally subject to inspection and hazard control. Where information is available, however, reports from volunteer and other noninspected sites will be of value.

NOTE: A SEPARATE FORM SHOULD BE COMPLETED FOR EACH INDIVIDUAL FAILURE. Inclusion of more than one failure on a report prevents correlation of data unless all details are identical.

Additional forms may be obtained from your headquarters or by writing to the following address:

Return to: Lee A. Paine
U.S.D.A. Forest Service
P.O. Box 245
Berkeley, California 94701

Commercial Phone: (415) 486-3158
FTS Phone: 449-3158

Figure 1—For data management, reports of tree failures and accidents are submitted on a form patterned after the U.S. Forest Service Form PSW-4600-3. As shown here, the arrangement of the original form has been modified to indicate the ADP card location of codes for each item. Labeling of the spaces (see "Format for ADP Cards") shows the card number (1 or 2) at left, followed by the column numbers of the appropriate field. Use of this modified form eliminates a step in the process of ADP card preparation: cards are punched directly from the report form rather than from codes transcribed to a worksheet. (Note: For convenient duplication, master copies of the form are provided at the end of this report.)

saving in time required for the coding and punching process results, but accuracy may be reduced somewhat if the transcriber would otherwise recheck the coding. The ERROR CHECK program will detect many coding mistakes in the punched cards.

Problems in Interpreting Reports

Every effort should be made to obtain complete and accurate information for all entries on the Report of Tree Failure before coding is started. This may require additional communication with the office or individual responsible for the report, or judicious reference to earlier reports from the same site or area. It is essential to check the comments on any attached letters to see if they agree with information given in the report itself. The genus (and species), the DBH (tree diameter at breast height), and the class of failure are especially important. If any of these items is unobtainable, the report loses much of its value and may not be worth coding. A report covering a serious accident is an exception—available data, even if incomplete, should be coded.

In general, the coding sequence should follow the order of items on the Report of Tree Failure *(fig. 1)*. The code lists in this manual are arranged for convenient use. The long lists—species, forest type, agency, and state and county—are given in separate sections in the sequence in which they occur on the report. The shorter code lists for all other lettered items on the report are given in the opening section titled "Codes for Failure Report—Outline." Reference to these short lists is not often required, because most of these codes are either reported numerically (such as approximate DBH,or follow a sequential pattern determined by the number of entries for the item. (Thus, under item B, class of mechanical failure, an entry for upper bole is coded as 1, for lower bole as 2, and so on.)

Two departures from the general arrangement have been made for convenience in use of the manual. The list titled "Tree Species Codes—Numeric" is used in assigning codes to new species and to avoid assignment of the same code to more than one species. It is placed at the end of the manual so that it will not be confused with the more frequently used list, "Tree Species Codes—Alphabetic." The "Target Value Guide" is used in coding most accidents, and is therefore placed near the front of the manual.

Note that the lists given in this manual are not complete in the absolute sense. Generally, they represent only the species, sites, etc., for which data have been received in the past. Provision for expansion is evident in some lists (ex.: species); in others, new, unlisted code numbers should be established by analogy with related listed codes.

In assigning codes to information given in reports, be a bit skeptical. Most reporting errors arise from misunderstandings. You will soon become familiar with common misinterpretations, and will learn to reconstruct the reports in terms of usable information.

Any changes on the report form from the way it was submitted should be marked in red (and initialed), with the original lined out. That will make it clear that the change was intentional and was made by the coder.

The following notes are referenced to the Report of Tree Failure.

Validity of Failure

Inspect each failure report first to insure that it represents a true mechanical failure (not a tree mortality without failure, or hazard control work prior to failure).

Reports of dead or dying trees which apparently do not represent actual mechanical failures should not be coded unless the failures can be verified by a followup to the originator. Indications that the report may not represent a true failure include:

- No class of failure reported
- Tree dead (snag) reported under defect or fault
- No contributing factors noted
- Notes in the comments section: for example, "14 trees died from spring floods," or "many trees dead or dying; will be removed before recreation season."

Multiple Reports

Although directions on the form request that only one tree failure per form be reported, "multiple" reports are occasionally received—that is, a number of failures are recorded on a single form. Such reports frequently represent a catastrophe.

For a multiple report, try to code each tree accurately for punching as a separate report. The simplest procedure is to fill out and number an additional blank form for each tree failure coded. If data are insufficient to code all trees individually, and additional information cannot be obtained from the originator, fill out only as many forms as there are individual failures justified by reliable data. On each form, for the coding item "number of trees," enter the sum of 1 (for the failure coded) plus a proportional share of the number of failures not coded. The total "number of trees" coded from a multiple report will thus include the individually coded failures plus associated uncoded failures.

Unknown or Unreported Data

Missing information decreases the value of a report for analysis. Do your best to reconstruct each item of information on the report form before coding it as unknown. If an item is properly reported as unknown, or not reported at all, code it using 9's. (Ex.: if age is left blank on the report, code as 999.)

There is one exception: in item C, tree defect or fault, the code for "unknown" is 16. "Unknown" classification (9's) is not "permissible" for certain items. This means that the item will be identified as illegal in the ERROR CHECK program if it is coded as unknown. If no other code can be entered, decide whether the report should be included in the data file or discarded because it is incomplete. Items on the report for which "unknown" is not normally permissible include the following:

Reporting Agency: If the lowest administrative level for the reporting agency is not given and cannot be traced, do not use 9's. Instead, code the report as though it had come from the next higher level of that agency. (Ex.: for a report from the Tonto National Forest in Arizona giving no Ranger District, code the agency as Tonto NF, or 01307 00. If, however, it is apparent from the campground name and the county that the report is actually from the Pleasant Valley Ranger District, write in the full code, which is 01307 05.)

A. Under *tree and stand:* Species, approximate DBH of tree
B. *Class of mechanical failure*
E. Under *time and location of incident:* Site open; Year; State and county
G. *Site category*
H. *Property or person affected*
I. *Consequences* (Exception: "Cleanup work required" is always coded 9 for a failure without accident.)

Certain other items not provided for on the report but requiring coding should not normally be coded as unknown:

Estimated value of property involved in accident.

Total value for property and individuals in accident. If no accident is involved, these items are not coded.

Dimensions Exceeding Field Size

For certain data items shown as dimensions (age, DBH, loss estimate, etc.), values reported may exceed the number of digits allowed (see "Format for ADP Cards"). For these, use the appropriate number of 9's followed by an 8. (Ex.: for a report on a 2,000-year-old redwood, code the age as 998, even though the true age exceeds the allowed three digits. Do not code as 999, which would indicate an unknown value. In this procedure, be sure to copy the true figure—here "2,000 years old"—into the comments section for punching on the ADP card.)

Coding Specific Items

Certain items present difficulties in coding. These suggestions may be helpful. The items on the report form are discussed under the major headings on the form itself. Additional items that must be coded (Failure Category, Estimated Property Value, Total Value, and Number of Trees) are also discussed.

Reporting Agency and Unit

Reports by an agency of failures which occurred on private land or on land of another agency usually should indicate the actual land ownership (ex.: "Private" or "Kale County Park"). Exceptions occur when the reporting agency has assumed some administrative or legal responsibility for the site, including inspection or maintenance, and could be held liable for damages (ex.: State and Private Forestry, U.S. Forest Service). The reporting agency should then be coded, to permit retrieval and analysis of all pertinent data by the managing agency. The actual category of ownership is coded under item F, Land Ownership (see below).

A. Tree and Stand

Species—Coding the tree species is often a source of trouble, largely because there may be many common names for a single species, and because ranges overlap among similar species. Experience simplifies this task. A number of reference books provide common names, genus and species, and natural ranges for trees native to the United States. Although codes allow for broader classifications, try to determine the species of the failing tree or, at the very least, the genus. If the genus is given, but not species, the tree may be coded as an unidentified species for that genus. (Ex.: if the report shows pine, and the species cannot be determined, code it as "pine, unidentified": 010). If the genus cannot be determined and the tree cannot even be classified as either softwood or hardwood, do not code the report.

DBH—For diameter at breast height, be sure that the figure is coded in inches rather than feet or meters. (Ex.: if DBH is given as 3 and age as 175 years, 3 feet may usually be assumed to be intended, rather than 3 inches. Code as 36 inches.)

Age—When age is not reported, code as 999.

Forest type—The codes provided here cover broad groupings of forest types. Many agencies have their own systems of forest types, which can be interpreted in terms of our classification. For example, types are often given initials denoting economically important species, such as DF (Douglas-fir). Again, the "type" may be denoted by timber grade, such as grade B sawtimber. Assignment of our type codes should be determined according to (1) species of tree, (2) associated species, (3) location, (4) past reports from the same location, and (5) the type specifications given under "Forest Type Descriptions."

Stand age class—General rule of thumb: if a report does not show all-age, but does show two or more other age classes, code as the oldest age class shown; if all-age is shown as well as young, mature, or overmature, code as all-age.

Elevation—Elevation is occasionally reported in meters above sea level; this value must be converted to feet before coding. Check other sources for elevation if in doubt. (1 meter = 3.28 feet.) Note, however, that the abbreviation msl stands for mean sea level and does not specify the unit of measurement.

B. Class of Failure

The reported class of mechanical failure should be taken at face value unless there is reason to believe that the reporter misunderstands the breakdown of classes (as when a note in the comments indicates a class of failure other than that reported). Occasionally more than one class of failure is checked on a single failure report. Since only one can be coded, choose whichever is listed first in the following sequence: uprooting, butt, lower bole, upper bole.

C. and D. Tree Defect and Contributing Factors

Predisposing defects and contributing factors checked on the form should not be accepted when it is clear that they were not directly and immediately involved in the mechanical failure of the tree.

Occasionally, the defects or factors checked contributed to earlier damage or decadence of some part of the tree, but not immediately to the reported failure. Insects, for example, may kill a tree, but are seldom the proximal cause of failure. Deterioration and decay more commonly cause the critical loss of strength and stability. Involvement of related but more remote factors, such as insect kill, may be written into the Comments and underlined for punching on the ADP card.

Reports are sometimes submitted with information in defects (C) or contributing factors (D) which apparently conflicts with the failure class that was reported. (Ex.: a limb failure may be reported as associated with soil saturation. Soil saturation would normally contribute only to uprooting of the tree. Similarly, a butt failure would not be caused by a dead top.) If such conflicts appear to result from misinterpretation, assume that the failure class is correct, delete the conflicting defect or contributing factor as nonresponsive, and code as unknown, unless other appropriate defects or contributing factors are indicated.

Potentially conflicting associations of defects and contributing factors are identified by the ERROR CHECK program, as follows:

Class of failure	*Defects*	*Contributing factors*
Upper bole	Twin bole or basal fork	Erosion Soil saturation Stream bank erosion Shallow rooting
Lower bole	Fork or multiple top Dead top or branch	Erosion Soil saturation Stream bank erosion Shallow rooting
Butt	Fork or multiple top Dead top or branch	Erosion Soil saturation Stream bank erosion Shallow rooting
Limb	Sweep Lean Twin bole or basal fork	Erosion Soil saturation Stream bank erosion Shallow rooting
Uprooting	Fork or multiple top Twin bole or basal fork Dead top or branch Canker, rust Canker, mistletoe	

Tree-striking-tree failures present special problems. In this type of failure, a tree fails and strikes a second tree as it falls (or, more rarely, several trees), causing the failure of the second tree. Only the tree which was hit is coded with tree-striking-tree (7) as a contributing factor. The report number of the first tree, which did the striking, should be included in the comments field of the report for the second tree. If wind is also given as a contributing factor for the second tree (the tree which was struck), it should be accepted only if the class of failure was lower bole, butt, or uprooting.

When two trees are involved in an accident through one tree striking another, the accident and the full amount of damage are attributed to the first failing tree.

"Unknown" should be accepted only if no other defect (or contributing factor) is checked. (Ex.: a reporter may check both ''wind'' and ''unknown'' as contributing factors. Because wind is reported as contributing to the failure, ''unknown'' should be deleted, and ''wind'' should be coded.)

E. Time and Location

Approximate hour—If approximate hour is reported as midnight, code as 24.

Month and year—Month and year are often given in vague terms, such as ''winter 1970.'' Make an estimate (0170), if justified, or code the month as ''unknown'' (9970).

Site open—If ''site open for public use'' is reported negative, accept it as correct unless there is some clear indication that the site was indeed being utilized.

F. Land Ownership

Telephone and power line rights-of-way are coded as public utilities.

G. Site Category

Be sure that sites are correctly described.

Other established public use site—Includes parking lots.

Special use site—Includes a ski lift belonging to a permittee-concessionaire.

If ''other'' is checked but description shows that the site belongs in a specific category, correct the report. (Ex.: report shows ''Ranger's house'' or ''Fern Grove Trail.'' Change the entry and code it as ''residence site'' or ''marked trail.'')

H. Property or Person Directly Affected

Agency—Code as ''agency'' if there were no significant consequences resulting from the failure, or if consequences were damage to agency property. This does not include property owned by recreationists or profit-oriented installations.

Recreationist—Property or person affected is sometimes listed on a failure report as ''recreationist'' despite the fact that no recreationist was directly affected. Unless there was some injury or loss to a recreationist, the person affected is not ''recreationist.''

Code as ''recreationist'' if damaged property was owned by individuals and not used for income production (ex.: summer cabins on a Forest Service summer home tract). All injuries or fatalities are coded as recreationist losses regardless of incidental damage to agency or commercial property.

Some accidents involve both agency and recreationist property loss. Such losses are coded ''recreationist'' unless the agency sustains 80 percent or more of the total damage. (Ex.: if a tree falls and destroys an agency cabin for a $2,500 loss and a recreationist's car for a $500 loss, the loss is coded as ''agency'' because the agency has sustained 83 percent of the $3,000 loss. However, if a tree fails causing a $1,000 nonrecreationist loss, and a $500 recreationist loss, the total $1,500 loss is coded as a recreationist loss. Even though the recreationist sustained only 33 percent of the loss, the agency sustained less than the 80 percent guideline.)

Permittee-Concessionaire—Code as ''permittee-concessionaire'' when, for example, a tree fails and hits a gas station, a gift shop in a park, or a ski lift. These would not be recreationist losses unless a recreationist were directly involved with property loss or injury.

I. Consequences

Cleanup work required—The option to check this term was included on the report form to insure that only failures of appropriate size would be reported when no damage or injury occurred. If damage or injury *are* reported, code this item as 0, whether or not cleanup work is reported. Otherwise, code it as 9. Note again that if 9 is used (that is, no damage or injury), ''recreationist'' cannot be coded as the person affected under item H.

Property damaged—For the description of property damaged enter a brief (five letter) noun or abbreviation describing the object damaged. If no information is given about the type of damaged property, enter XXXXX to indicate that the description was not overlooked by the encoder.

Property loss—Whenever property damage is incurred, a good estimate of the loss must be assigned if not reported. If property cannot be identified, assign a minimal loss of $10 providing that property was obviously damaged and that no further information is available.

Medical attention—When medical attention is required, it must also be coded as an injury. The converse is not necessarily true (a reported injury does not necessarily require medical attention).

Property Value and Total Value

These two items are not shown on the Failure Report. Value of the property must be estimated from the best available sources and entered on the report form (see Target Value Guide). The assigned property value should not exceed the maximum expected loss which could result from an uprooted 70-inch softwood falling on the reported target. A second entry, total value, is the sum of the property value and the amounts shown for any injuries requiring medical attention or resulting in fatalities, as given in the Target Value Guide.

Failure Category

This item is not shown on the Failure Report.

Normal (forest, single)—The term applies to a single failure occurring on managed or occupied sites in a forested or wooded (nonurban) environment.

Catastrophe—These failures may occur on forest or urban sites.

1. Minimum number of failures is 16.
2. All failures occur at one location at the same time. Usually reports show same agency (Region, Forest, and District), hour (± 3 hours for failure due to wind), month, year, state, and county.
3. Failures usually involve wind, tree-striking-tree, or both. Rain or snow may be contributing factors.

In general, use discretion in identifying groups of failures as catastrophes.

Urban—The term applies to a single failure occurring on a site assigned to day use by urban populations. The significant characteristics are more intensive management of the site and heavy utilization. Urban sites may include city parks, regional parks, street parkways, some county parks and many historical sites. Usually an urban site is considered a "landscape" type, but regional and county parks may be ecologically defined forest types.

Number of Trees

This item is not shown on the Failure Report. A single failure is counted as 1. On a multiple report, however, other failures may be indicated which cannot be coded individually. The number of associated uncoded failures plus one is entered as "number of trees."

J. Name of Site and Comments

Underline for coding significant information not otherwise coded on the report, up to a maximum of 35 characters (letters, numbers, and spaces). The name of the specific site is especially useful. Comments on targets, wind conditions, tree age, etc., may be added. Make liberal use of abbreviations, but be sure they are clear (ex.: CG for campground).

Format for ADP Cards

The ADP card used for the data management system has the standard 80 columns. One failure report requires two data cards; certain items are entered on both cards for convenience.

Card punching may be done directly from the report form if the modified version shown in *figure 1* is used. Otherwise, data from the form are transcribed to an 80-column worksheet, using the card format. In this procedure, to help maintain punching accuracy, a set of two worksheets is used, one for each of the two cards needed for each failure report.

On the data worksheets and cards, a "field" of one or more columns is set aside for each piece of information on the report form. The number of columns in a field varies according to the length of the code established for that information. The resulting fixed assignment of fields on the cards is the "card format."

ADP Card 1 Format

Columns	Content
1-5	Accession number
6	Data card number (enter 1)
7-9	Species of failing tree; 999 not permissible
11-12	Approximate DBH of tree; 99 not permissible
14-16	Approximate age of tree
18-19	Forest type
21	Stand age class
23-25	Elevation of site (divide by 100)
27	Class of mechanical failure; 9 not permissible
29-30	Defect or fault (lowest applicable code number)
32-33	Defect or fault (next higher applicable code number, if any)
35-36	Defect or fault (next higher applicable code number, if any)
38	Contributing factor (lowest applicable code number)
40	Contributing factor (next higher applicable code number, if any)
42	Contributing factor (next higher applicable code number, if any)
44-45	Agency
46	Region
47-48	Forest or Park
50-51	District
52	Subunit designation when needed
53-54	Approximate hour (24-hour clock; midnight = 24 hours); do not use 00.
56-57	Month
58-59	Year; 99 not permissible
61-62	State; 99 not permissible
63-65	County; 999 not permissible
67	Site open for public use (yes 1, no 2); 9 not permissible
69	Land ownership
71	Site category; 9 not permissible
73	Property or person directly affected; 9 not permissible
75	Property damaged (1 or 0); 9 not permissible
77	Injuries (number of injuries or 0); 9 not permissible
79	Fatalities (number of fatalities or 0); 9 not permissible
80	Cleanup work required (9 or 0)

ADP Card 2 Format

Columns	Content
1-5	Accession number (same as on card 1)
6	Data card number (enter 2)
7	Property damaged (1 or 0)
9-13	Description of property damaged (use five X's if no description given)
14-18	Property loss estimate (if there is damage, a dollar estimate must be supplied)
20	Injuries (number of injuries or 0)
22	Medical attention required (number attended or 0)
24	Fatalities (number of fatalities or 0)
26	Failure category (normal=0, catastrophe=1, urban=2)
27-31	Estimated property value (use target value guide for accident); 99999 not permissible
32	Not currently in use; zero will print out on data listing
33-38	Total value (property+injury+fatality if accident); blank or max. 999998
40-42	Number of trees (1 plus any other trees not shown in coded data, but which failed at same time)
44-78	Comments (site name and other useful data or "no comments")
80	Cleanup work required = 9; if accident, enter 0; all recorded reports should be coded either 9 or 0

CODES FOR FAILURE REPORT - OUTLINE

SPECIES	SEE TREE SPECIES CODES - ALPHABETIC	
APPROXIMATE DBH OF TREE	01-98 (98 IF OVER 98 INCHES. 99 IS NOT PERMISSIBLE)	
APPROXIMATE AGE OF TREE	001-998 (998 IF OVER 998 YEARS. 999 IF UNKNOWN)	
FOREST TYPE	SEE FOREST TYPE CODES	
STAND AGE CLASS	OVERMATURE	1
STAND AGE CLASS	MATURE	2
STAND AGE CLASS	YOUNG-GROWTH	3
STAND AGE CLASS	ALL-AGE	4
STAND AGE CLASS	UNKNOWN	9
ELEVATION OF SITE	(DIVIDE ELEVATION BY 100. UNKNOWN = 999). 001-998	
CLASS OF FAILURE	UPPER BOLE (TOP HALF)	1
CLASS OF FAILURE	LOWER BOLE	2
CLASS OF FAILURE	BUTT (LOWER SIX FEET)	3
CLASS OF FAILURE	LIMB	4
CLASS OF FAILURE	ROOT (INCLUDING UPROOTING)	5
CLASS OF FAILURE	UNKNOWN (NOT PERMISSIBLE)	
DEFECT OR FAULT	ROT (TRUNK, LIMB, OR ROOT)	01
DEFECT OR FAULT	SWEEP	02
DEFECT OR FAULT	TREE DEAD-SNAG	03
DEFECT OR FAULT	FIRE WOUND	04
DEFECT OR FAULT	LEANING	05
DEFECT OR FAULT	LIGHTNING WOUND	06
DEFECT OR FAULT	MECHANICAL WOUND	07
DEFECT OR FAULT	CRACKS OR SPLITS	08
DEFECT OR FAULT	FORK OR MULTIPLE TOP	09
DEFECT OR FAULT	TWIN BOLE OR BASAL FORK	10
DEFECT OR FAULT	DEAD TOP OR BRANCH	11
DEFECT OR FAULT	WIDOW-MAKER OR HANG-UP	12
DEFECT OR FAULT	CANKER, RUST	13
DEFECT OR FAULT	CANKER, MISTLETOE	14
DEFECT OR FAULT	OTHER	15
DEFECT OR FAULT	UNKNOWN OR NONE	16
CONTRIB FACTORS	WIND	1
CONTRIB FACTORS	SNOW	2
CONTRIB FACTORS	EROSION	3
CONTRIB FACTORS	SOIL SATURATION	4
CONTRIB FACTORS	STREAM BANK EROSION	5
CONTRIB FACTORS	SHALLOW ROOTING	6
CONTRIB FACTORS	TREE STRIKING TREE	7
CONTRIB FACTORS	OTHER	8
CONTRIB FACTORS	UNKNOWN OR NONE	9
AGENCY AND UNIT	SEE AGENCY CODES	
APPROXIMATE HOUR	(99 IF UNKNOWN)	01-24
MONTH	(99 IF UNKNOWN)	01-12
YEAR	(LAST TWO DIGITS)	60-98
STATE	SEE STATE AND COUNTY CODES	01-50
COUNTY	SEE STATE AND COUNTY CODES	001-275

SITE OPEN	YES	1
SITE OPEN	NO	2
LAND OWNERSHIP	FEDERAL	1
LAND OWNERSHIP	STATE	2
LAND OWNERSHIP	OTHER PUBLIC	3
LAND OWNERSHIP	PRIVATE	4
LAND OWNERSHIP	PUBLIC UTILITY	5
LAND OWNERSHIP	UNKNOWN	9
SITE CATEGORY	ESTABLISHED CAMP OR PICNIC GROUND	1
SITE CATEGORY	OTHER ESTABLISHED PUBLIC USE SITE	2
SITE CATEGORY	VOLUNTEER SITE	3
SITE CATEGORY	MARKED TRAIL	4
SITE CATEGORY	SPECIAL USE SITE	5
SITE CATEGORY	ROADSIDE	6
SITE CATEGORY	RESIDENCE	7
SITE CATEGORY	OTHER	8
SITE CATEGORY	UNKNOWN CATEGORY NOT PERMISSIBLE	
PROP-PERSON	AGENCY	1
PROP-PERSON	RECREATIONIST	2
PROP-PERSON	FOREST INDUSTRY	3
PROP-PERSON	PERMITTEE-CONCESSIONAIRE	4
PROP-PERSON	OTHER	5
PROP-PERSON	CONTRACTOR	6
PROP-PERSON	PUBLIC UTILITY	7
PROP-PERSON	UNKNOWN PROP OR PERSON NOT PERMISSIBLE	
CONSEQUENCES	CLEANUP WORK REQUIRED (ENTER 0 IF DAMAGE OR INJURY RESULTED. OTHERWISE ENTER 9. DO NOT CODE TREE IF FAILURE DID NOT CAUSE ACCIDENT AND WAS TOO SMALL TO REQUIRE CLEANUP).	0 OR 9
CONSEQUENCES	PROPERTY DAMAGED	0 (NONE) OR 1
CONSEQUENCES	PROPERTY DESCRIPTION (ALPHABETIC)	FIVE SPACES
CONSEQUENCES	PROPERTY LOSS ESTIMATE (DOLLARS)	00001-99998
CONSEQUENCES	NUMBER OF INJURIES	0 OR 1-3
CONSEQUENCES	MEDICAL ATTENTION REQUIRED (NUMBER)	0 OR 1-3
CONSEQUENCES	NUMBER OF FATALITIES	0 OR 1-3
NUMBER OF TREES	(NOT SHOWN ON REPORT FORM)	001-998
NAME OF SITE	INCLUDE IN COMMENTS FIELD WHEN CODING	
COMMENTS	ALPHABETIC: INCLUDE NAME OF SITE, UNUSUAL WEATHER, 'OTHER' DEFECTS, CONTRIBUTING FACTORS, ETC. (LIMITED TO 34 SPACES)	
PROPERTY VALUE	(NOT SHOWN ON REPORT FORM). DOLLAR VALUE OF PROPERTY IF ACCIDENT OCCURRED. SEE TARGET VALUE GUIDE.	00001-99998
TOTAL VALUE	(NOT SHOWN ON REPORT FORM) SUM OF DOLLAR VALUES (PROPERTY, INJURY, FATALITY) FOR TARGETS AFFECTED BY ACCIDENT.	000001-999998
FAILURE CATEGORY	(NOT SHOWN ON REPORT FORM)	
	NORMAL (FOREST,SINGLE)	0
	CATASTROPHE	1
	URBAN (SINGLE)	2

TARGET VALUE GUIDE

Use actual value (maximum possible loss) if known. If reported loss is greater than value guidelines, use loss as reported and adjust value accordingly. Update and modify values to best represent local reporting sites.

	Suggested value (Maximum possible loss from an uprooted 70-inch DBH softwood)
POWERLINE	$ 500
UTILITY POWER LINE	75
TELEPHONE LINE	50
CHAIN LINK OR CYCLONE FENCE	300
BARBED WIRE FENCE OR RAIL FENCE	90
WATER OR SEWER LINE	200
TRASH CAN	20
SIGN	50
TOILET	1,000
COMFORT STATION	30,000[1]
PUMPHOUSE	5,000
CHANGE HOUSE	4,000
CHLORINATOR	2,000
SHED	500
FOOD LOCKERS	150
FIRE PIT	100
STOVE	100
PICNIC TABLE	300
CONCRETE PICNIC TABLE	500
TENT	70
CAMPSITE	1,337
TENT CABIN	2,000
1-ROOM VACATION CABIN	2,500
SUMMER HOUSE	5,000
BUILDING	5,000
PERMANENT RESIDENCE SITE	10,000
GARAGE	1,000
AUTO	2,000
WOOD GATE	150
BARRIER	35
TRAIL	400
FOOT BRIDGE (16')	1,000
ROAD	200
VEHICLE BRIDGE (20')	1,200
TRAILER, 2 WHEEL + CONTENTS	2,600
TRAILER, 4 WHEEL + CONTENTS	4,300
TRAILER, CONTENTS UNKNOWN	3,500
CAMPER	7,000
RECREATION VEHICLE - RV	45,000
TRUCK	3,000
OUTBOARD MOTOR	110
BOAT TRAILER OR CANOE	300
SKI LIFT	6,000
INJURY	2,700[2]
FATALITY	45,000

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[1] NEW FACILITIES COST $40,000 1/78

[2] ONLY IF MEDICAL TREATMENT NEEDED

TREE SPECIES CODES - ALPHABETIC[1]

Softwood Species Codes

000	UNIDENTIFIED GENERA OF SOFTWOODS	(AVOID USE OF 000)
001-499	ALL SOFTWOOD SPECIES	
211	ALASKA-CEDAR	CHAMAECYPARIS NOOTKATENSIS
200	CEDAR FAMILY, UNIDENTIFIED GENERA	
211	ALASKA-CEDAR	CHAMAECYPARIS NOOTKATENSIS
212	PORT-ORFORD-CEDAR	CHAMAECYPARIS LAWSONIANA
232	REDCEDAR, EASTERN	JUNIPERUS VIRGINIANA
221	REDCEDAR, WESTERN	THUJA PLICATA
455	STINKING-CEDAR (RARE)	TORREYA TAXIFOLIA
270	CYPRESS, UNIDENTIFIED	CUPRESSUS SPP.
	ARIZONA, GOWAN, MACNAB,	CUPRESSUS SPP.
	MODOC, MONTEREY, TECATE	CUPRESSUS SPP.
001	DOUGLAS-FIR	PSEUDOTSUGA MENZIESII
002	DOUGLAS-FIR, BIGCONE	PSEUDOTSUGA MACROCARPA
100-199	FIR SPP.	
100	FIR, UNIDENTIFIED	ABIES SPP.
108	FIR, BALSAM	ABIES BALSAMEA
107	FIR, BRISTLECONE	ABIES BRACTEATA
102	FIR, CALIFORNIA RED	ABIES MAGNIFICA
103	FIR, GRAND	ABIES GRANDIS
105	FIR, NOBLE	ABIES PROCERA
104	FIR, PACIFIC SILVER	ABIES AMABILIS
106	FIR, SUBALPINE, CORKBARK	ABIES LASIOCARPA
101	FIR, WHITE	ABIES CONCOLOR
350	HEMLOCK, UNIDENTIFIED	TSUGA SPP.
354	HEMLOCK, CAROLINA	TSUGA CAROLINIANA
353	HEMLOCK, EASTERN	TSUGA CANADENSIS
351	HEMLOCK, MOUNTAIN	TSUGA MERTENSIANA
352	HEMLOCK, WESTERN	TSUGA HETEROPHYLLA
202	INCENSE-CEDAR	LIBOCEDRUS DECURRENS
230	JUNIPER, UNIDENTIFIED	JUNIPERUS SPP.
231	JUNIPER, ALLIGATOR, CALIFORNIA,	JUNIPERUS SPP.
231	JUNIPER, COMMON, ONE-SEED, PINCHOT,	JUNIPERUS SPP.
231	JUNIPER, ROCKY MTN, UTAH, WESTERN	JUNIPERUS SPP.
400	LARCH, UNIDENTIFIED	LARIX SPP.
402	LARCH, SUBALPINE	LARIX LYALLI
401	LARCH, WESTERN	LARIX OCCIDENTALIS

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[1] WHENEVER A NEW SPECIES IS ADDED TO THE FOLLOWING LIST, MAKE THE CHANGES IN THE NUMERIC CODE LIST AND IN THE ERROR PROGRAM AT THE SAME TIME.

010-099	PINE SPP.	
010	PINE, UNIDENTIFIED	PINUS SPP.
037	PINE, APACHE, CHIHUAHUA	P. SPP.
040	PINE, BRISTLECONE, FOXTAIL	P. SPP.
026	PINE, LIMBER, WHITEBARK	P. SPP.
027	PINE, PINYON, MEXICAN PINYON, PARRY	P. SPP.
027	PINE, PINYON, SINGLELEAF PINYON	P. SPP.
035	PINE, ALEPPO	P. HALEPENSIS
025	PINE, BISHOP	P. MURICATA
021	PINE, COULTER	P. COULTERI
023	PINE, DIGGER	P. SABINIANA
032	PINE, EASTERN WHITE	P. STROBUS
034	PINE, ITALIAN STONE	P. PINEA
036	PINE, JACK	P. BANKSIANA
012	PINE, JEFFREY	P. JEFFREYI
024	PINE, KNOBCONE	P. ATTENUATA
030	PINE, LOBLOLLY	P. TAEDA
015	PINE, LODGEPOLE, BEACH, COAST, SHORE	P. CONTORTA
029	PINE, LONGLEAF	P. PALUSTRIS
022	PINE, MONTEREY	P. RADIATA
031	PINE, PITCH	P. RIGIDA
039	PINE, POND	P. SEROTINA
011	PINE, PONDEROSA	P. PONDEROSA
016	PINE, RED	P. RESINOSA
028	PINE, SHORTLEAF	P. ECHINATA
038	PINE, SLASH	P. ELLIOTTII
013	PINE, SUGAR	P. LAMBERTIANA
025	PINE, TORREY	P. TORREYANA
033	PINE, VIRGINIA	P. VIRGINIANA
025	PINE, WASHOE	P. WASHOENSIS
014	PINE, WESTERN WHITE	P. MONTICOLA
212	PORT-ORFORD-CEDAR	CHAMAECYPARIS LAWSONIANA
221	REDCEDAR, WESTERN	THUJA PLICATA
232	REDCEDAR, EASTERN	JUNIPERUS VIRGINIANA L.
005	REDWOOD, COAST	SEQUOIA SEMPERVIRENS
007	REDWOOD, DAWN	METASEQUOIA
006	SEQUOIA, GIANT	SEQUOIADENDRON GIGANTEA
300	SPRUCE, UNIDENTIFIED	PICEA SPP.
301	SPRUCE, ENGELMANN	PICEA ENGELMANNII
303	SPRUCE, BLACK	PICEA MARIANA
305	SPRUCE, BLUE	PICEA PUNGENS
306	SPRUCE, BREWER	PICEA BREWERIANA
307	SPRUCE, RED	PICEA RUBENS
302	SPRUCE, SITKA	PICEA SITCHENSIS
304	SPRUCE, WHITE, PARSILD	PICEA GLAUCA
455	STINKING-CEDAR (RARE)	TORREYA TAXIFOLIA
403	TAMARACK	LARIX LARICINA
450	TAXUS, UNIDENTIFIED	TAXUS SPP.
220	THUJA, UNIDENTIFIED	THUJA SPP.
454	TORREYA, CALIFORNIA	TORREYA CALIFORNICA
455	TORREYA, FLORIDA	TORREYA TAXIFOLIA

450	YEW, UNIDENTIFIED	
451	YEW, PACIFIC	TAXUS BREVIFOLIA
452	YEW, CANADIAN	TAXUS CANADENSIS
453	YEW, FLORIDA	TAXUS FLORIDANA

Hardwood Species Codes

500-799	HARDWOOD SPECIES EXCLUSIVE OF OAKS	
500	UNIDENTIFIED HARDWOOD SPECIES	(AVOID USE OF 500)
521	ACACIA, UNIDENTIFIED	ACACIA SPP.
520	ACACIA, BROADLEAF	ACACIA LATIFOLIA
730	ACACIA, CATCLAW	ACACIA GREGGII
731	ACACIA, SWEET	ACACIA FARNESIANA
530	AILANTHUS	AILANTHUS ALTISSIMA
501	ALDER, UNIDENTIFIED	ALNUS SPP.
616	ALDER, EUROPEAN	ALNUS GLUTINOSA
572	ALDER, RED	ALNUS RUBRA
617	ALDER, THINLEAF	ALNUS TENNIFOLIA
571	ALDER, WHITE	ALNUS RHOMBIFOLIA
547	APPLE, UNIDENTIFIED	MALUS SPP.
700	APPLE, COMMON	MALUS PUMILA
701	APPLE, SOUTHERN CRAB	MALUS ANGUSTIFOLIA
702	APPLE, SWEET CRAB	MALUS CORONARIA
502	ASH, UNIDENTIFIED	FRAXINUS SPP.
773	ASH, BLACK	FRAXINUS NIGRA
774	ASH, BLUE	FRAXINUS QUADRANGULATA
775	ASH, CAROLINA	FRAXINUS CAROLINIANA
776	ASH, GREEN	FRAXINUS PENNSYLVANICA
777	ASH, OREGON	FRAXINUS LATIFOLIA
778	ASH, WHITE	FRAXINUS AMERICANA
505	ASPEN, UNIDENTIFIED	POPULUS SPP.
580	ASPEN, BIGTOOTH	POPULUS GRANDIDENTATA
503	ASPEN, QUAKING	POPULUS TREMULOIDES
615	ATHEL	TAMARIX ARTICULATA
541	BASSWOOD, UNIDENTIFIED	TILIA SPP.
765	BASSWOOD, AMERICAN	TILIA AMERICANA
766	BASSWOOD, WHITE	TILIA HETEROPHYLLA
567	BAY, SWEET (NOT SWEETBAY)	LAURUS NOBILIS
527	BAYBERRY, PACIFIC	MYRICA SPP.
522	BEECH, UNIDENTIFIED	FAGUS SPP.
636	BEECH, AMERICAN	FAGUS GRANDIFOLIA
637	BEECH, EUROPEAN	FAGUS SYLVATICA
573	BEECH, BLUE	CARPINUS CAROLINIANA
504	BIRCH, UNIDENTIFIED	BETULA SPP.
606	BIRCH, GRAY	BETULA POPULIFOLIA
607	BIRCH, PAPER	BETULA PAPYRIFERA
608	BIRCH, RIVER	BETULA NIGRA
609	BIRCH, SWEET	BETULA LENTA
610	BIRCH, WATER	BETULA OCCIDENTALIS
611	BIRCH, YELLOW	BETULA ALLEGHANIENSIS

560	BLUEBLOSSOM	CEANOTHUS THYRSIFLORUS
750	BOXELDER	ACER NEGUNDO
508	BUCKEYE, CALIFORNIA	AESCULUS CALIFORNICA
760	BUCKEYE, OHIO	AESCULUS GLABRA
761	BUCKEYE, YELLOW	AESCULUS OCTANDRA
513	BUCKTHORN, CALIFORNIA	RHAMNUS CALIFORNICA
544	BUCKTHORN, CASCARA	RHAMNUS PURSHIANA
591	BUTTERNUT	JUGLANS CINEREA
512	CALIFORNIA-BAY (BELOW 5000 FT)	UMBELLULARIA CALIFORNICA
512	CALIFORNIA-LAUREL (BELOW 5000 FT)	UMBELLULARIA CALIFORNICA
560	CALIFORNIA-LILAC	CEANOTHUS THYRSIFLORUS
549	CAROB	CERATONIA SILIQUA
544	CASCARA	RHAMNUS PURSHIANA
542	CATALPA, UNIDENTIFIED	CATALPA SPP.
780	CATALPA, NORTHERN	CATALPA SPECIOSA
781	CATALPA, SOUTHERN	CATALPA BIGNONIOIDES
764	CEANOTHUS, SPINY	CEANOTHUS SPINOSUS
548	CHERRY, UNIDENTIFIED	PRUNUS SPP.
705	CHERRY, BLACK	PRUNUS SEROTINA
706	CHERRY, HOLLYLEAF	PRUNUS ILICIFOLIA
708	CHERRY, PIN	PRUNUS PENSYLVANICA
568	CHESTNUT, UNIDENTIFIED	CASTANEA SPP.
640	CHESTNUT, AMERICAN	CASTANEA DENTATA
641	CHESTNUT, CHINESE	CASTANEA MOLLISIMA
642	CHESTNUT, JAPANESE	CASTANEA CRENATA
643	CHESTNUT, SPANISH	CASTANEA SATIVA
552	CHINABERRY	MELIA AZEDARACH
650	CHINKAPIN, UNIDENTIFIED	CASTANOPSIS SPP.
651	CHINKAPIN, ALLEGHENY	CASTANOPSIS PUMILA
514	CHINKAPIN, GOLDEN	CASTANOPSIS CHRYSOPHYLLA
709	CHOKECHERRY, COMMON	PRUNUS VIRGINIANA
561	CHRISTMASBERRY	PHOTINIA ARBUTIFOLIA
545	COFFEETREE, KENTUCKY	GYMNOCLADUS DIOICUS
505	COTTONWOOD, UNIDENTIFIED	POPULUS SPP.
581	COTTONWOOD, BLACK	POPULUS TRICHOCARPA
582	COTTONWOOD, EASTERN	POPULUS DELTOIDES
556	COTTONWOOD, FREMONT	POPULUS FREMONTII
583	COTTONWOOD, SWAMP	POPULUS HETEROPHYLLA
680	CUCUMBERTREE	MAGNOLIA ACUMINATA
516	DOGWOOD, UNIDENTIFIED	CORNUS SPP.
768	DOGWOOD, FLOWERING	CORNUS FLORIDA
769	DOGWOOD, PACIFIC	CORNUS NUTTALLII
767	DOGWOOD, RED-OSIER	CORNUS STOLONIFERA

526	ELDER, UNIDENTIFIED (NOT BOXELDER)	SAMBUCUS SPP.
526	ELDERBERRY, UNIDENTIFIED	SAMBUCUS SPP.
786	ELDER, AMERICAN	SAMBUCUS CANADENSIS
789	ELDERBERRY, BLUE	SAMBUCUS GLAUCA
787	ELDERBERRY, DESERT	SAMBUCUS MEXICANA
787	ELDER, MEXICAN	SAMBUCUS MEXICANA
788	ELDER, PACIFIC RED	SAMBUCUS CALLICARPA
511	ELM, UNIDENTIFIED	ULMUS SPP.
655	ELM, AMERICAN	ULMUS AMERICANA
656	ELM, CEDAR	ULMUS CRASSIFOLIA
661	ELM, CHINESE	ULMUS PARVIFOLIA
657	ELM, RED	ULMUS SEROTINA
658	ELM, ROCK	ULMUS THOMASII
659	ELM, SLIPPERY	ULMUS RUBRA
660	ELM, WINGED	ULMUS ALATA
509	EUCALYPTUS, UNIDENTIFIED	EUCALYPTUS SPP.
531	FIG, UNIDENTIFIED	FICUS SPP.
676	FIG, COMMON	FICUS CARICA
677	FIG, FLORIDA STRANGLER	FICUS AUREA
678	FIG, SHORTLEAF	FICUS LAEVIGATE
533	GOLDENCHAIN TREE	LABURNUM WATERERI
524	HACKBERRY, UNIDENTIFIED	CELTIS SPP.
665	HACKBERRY	CELTIS OCCIDENTALIS
666	HACKBERRY (SUGARBERRY)	CELTIS LAEVIGATA
551	HAWTHORN, UNIDENTIFIED	CRATAEGUS SPP.
720	HAWTHORN, BLACK	CRATAEGUS DOUGLASII
721	HAWTHORN, COCKSPUR	CRATAEGUS CRUS-GALLI
630	HAZEL, UNIDENTIFIED	CORYLUS SPP.
631	HAZEL, AMERICAN	CORYLUS AMERICANA
632	HAZEL, BEAKED	CORYLUS ROSTRATA
633	HAZEL, CALIFORNIA	CORYLUS CORNUTA
634	HAZEL, GIANT	CORYLUS MAXIMA
555	HERCULES-CLUB TREE	ZANTHOXYLUM CLAVA-HERCULIS
525	HICKORY, UNIDENTIFIED	CARYA SPP.
596	HICKORY, BITTERNUT	CARYA CORDIFORMIS
597	HICKORY, BLACK	CARYA TEXANA
598	HICKORY, MOCKERNUT	CARYA TOMENTOSA
599	HICKORY, PIGNUT	CARYA GLABRA
600	HICKORY, SHAGBARK	CARYA OVATA
601	HICKORY, SHELLBARK	CARYA LACINIOSA
540	HOLLY, UNIDENTIFIED	ILEX SPP.
745	HOLLY, AMERICAN	ILEX OPACA
746	HOLLY, CAROLINA	ILEX AMBIGUA
747	HOLLY, GEORGIA	ILEX LONGIPES
561	HOLLYBERRY	PHOTINIA ARBUTIFOLIA
738	HONEYLOCUST, UNIDENTIFIED	GLEDITSIA SPP.
739	HONEYLOCUST	GLEDITSIA TRIACANTHOS
740	HONEYLOCUST, TEXAS	GLEDITSIA TEXANA
625	HOPHORNBEAM, UNIDENTIFIED	OSTRYA SPP.
626	HOPHORNBEAM, EASTERN	OSTRYA VIRGINIANA
627	HOPHORNBEAM, KNOWLTON (WESTERN)	OSTRYA KNOWLTONII

573	HORNBEAM, AMERICAN	CARPINUS CAROLINIANA
762	HORSECHESTNUT	AESCULUS HIPPOCASTANUM
535	IRON TREE	METROSIDEROS TOMENTOSA
627	IRONWOOD (ALSO OTHER GENERA)	OSTRYA KNOWLTONII
737	JUDAS-TREE	CERCIS CANADENSIS
794	LAUREL, UNIDENTIFIED (PUERTO RICO)	LAURACEAE
528	LAUREL, AMERICAN (7000-12000 FT)	KALMIA LATIFOLIA
567	LAUREL, GRECIAN	LAURUS NOBILIS
566	LAURELCHERRY, MYRTLE	PRUNUS MYRTIFOLIA
541	LINDEN, UNIDENTIFIED	TILIA SPP.
518	LOCUST, UNIDENTIFIED	ROBINIA SPP.
569	LOCUST, BLACK	ROBINIA PSEUDOACACIA
515	MADRONE, UNIDENTIFIED	ARBUTUS SPP.
772	MADRONE, PACIFIC	ARBUTUS MENZIESII
565	MAGNOLIA, UNIDENTIFIED	MAGNOLIA SPP.
681	MAGNOLIA, BIGLEAF	MAGNOLIA MACROPHYLLA
682	MAGNOLIA, FRASER	MAGNOLIA FRASERI
683	MAGNOLIA, SOUTHERN	MAGNOLIA GRANDIFLORA
685	MAGNOLIA, SWEETBAY	MAGNOLIA VIRGINIANA
684	MAGNOLIA, UMBRELLA	MAGNOLIA TRIPETALA
792	MANZANITA, EASTWOOD	ARCTOSTAPHYLOS GLANDULOSA
506	MAPLE, UNIDENTIFIED	ACER SPP.
750	BOXELDER	ACER NEGUNDO
751	MAPLE, BIGLEAF	ACER MACROPHYLLUM
752	MAPLE, BLACK	ACER NIGRUM
753	MAPLE, RED	ACER RUBRUM
754	MAPLE, ROCKY MOUNTAIN	ACER GLABRUM
755	MAPLE, SILVER	ACER SACCHARINUM
756	MAPLE, STRIPED	ACER PENSYLVANICUM
757	MAPLE, SUGAR	ACER SACCHARUM
536	MESQUITE, UNIDENTIFIED	PROSOPIS SPP.
574	MESQUITE, COMMON	PROSOPIS JULIFLORA
528	MOUNTAIN-LAUREL (7000-12000 FT)	KALMIA LATIFOLIA
538	MULBERRY, UNIDENTIFIED	MORUS SPP.
671	MULBERRY, BLACK	MORUS NIGRA
672	MULBERRY, RED	MORUS RUBRA
673	MULBERRY, TEXAS	MORUS MICROPHYLLA
674	MULBERRY, WHITE	MORUS ALBA
527	MYRICA SPP., UNIDENTIFIED	MYRICA SPP.
535	NEW ZEALAND CHRISTMAS TREE	METROSIDEROS TOMENTOSA
800	OAK -- SEE OAK SPECIES CODES --	
562	OLEANDER, COMMON	NERIUM OLEANDER
512	OREGON-MYRTLE (BELOW 5000 FT)	UMBELLULARIA CALIFORNICA
553	OSAGE-ORANGE	MACLURA POMIFERA

796	PALO COLORADO	CYRILLA RACEMIFLORA
717	PEAR, COMMON	PYRUS COMMUNIS
558	PEACH	PRUNUS PERSICA
550	PECAN	CARYA ILLINOENSIS
529	PEPPERTREE, CALIFORNIA	SCHINUS MOLLE
512	PEPPERWOOD (BELOW 5000 FT)	UMBELLULARIA CALIFORNICA
543	PERSIMMON, COMMON	DIOSPYROS VIRGINIANA
532	PISTACHE, TEXAS	PISTACIA TEXANA
744	POISON-SUMAC	TOXICODENDRON VERNIX
505	POPLAR, UNIDENTIFIED	POPULUS SPP.
584	POPLAR, BALSAM	POPULUS BALSAMIFERA
554	YELLOW-POPLAR	LIRIODENDRON TULIPIFERA
692	REDBAY	PERSEA BORBONIA
546	REDBUD, UNIDENTIFIED	CERCIS SPP.
736	REDBUD, CALIFORNIA	CERCIS OCCIDENTALIS
737	REDBUD, EASTERN	CERCIS CANADENSIS
539	REDGUM	LIQUIDAMBAR STYRACIFLUA
557	RUSSIAN-OLIVE	ELAEAGNUS ANGUSTIFOLIA
559	SANDALWOOD, BASTARD	MYOPORUM SANDWICENSE
690	SASSAFRASS	SASSAFRASS ALBIDUM
570	SILK-OAK	GREVILLEA ROBUSTA
790	SOAPBERRY, UNIDENTIFIED	SAPINDUS SPP.
563	SOURWOOD	OXYDENDRUM ARBOREUM
666	SUGARBERRY	CELTIS LAEVIGATA
537	SUMAC, UNIDENTIFIED	RHUS SPP.
743	SUMAC, STAGHORN	RHUS TYPHINA
527	SWEETBAY, SIERRA	MYRICA SPP.
539	SWEETGUM	LIQUIDAMBAR STYRACIFLUA
517	SYCAMORE, UNIDENTIFIED	PLATANUS SPP.
696	SYCAMORE, AMERICAN	PLATANUS OCCIDENTALIS
695	SYCAMORE, ARIZONA	PLATANUS WRIGHTII
697	SYCAMORE, CALIFORNIA	PLATANUS RACEMOSA
523	TAMARISK, UNIDENTIFIED	TAMARIX SPP.
783	TAMARISK, FIVE-STAMEN	TAMARIX PENTANDRA
784	TAMARISK, SMALLFLOWER	TAMARIX PARVIFLORA
510	TANOAK	LITHOCARPUS DENSIFLORA
561	TOYON	PHOTINIA ARBUTIFOLIA

530	TREE OF HEAVEN	AILANTHUS ALTISSIMA
554	TULIPTREE	LIRIODENDRON TULIPIFERA
534	TUPELO, UNIDENTIFIED	NYSSA SPP.
770	TUPELO, BLACK	NYSSA SYLVATICA
771	TUPELO, WATER	NYSSA AQUATICA
552	UMBRELLA-TREE	MELIA AZEDARACH
590	WALNUT, UNIDENTIFIED	JUGLANS SPP.
564	WALNUT, ARIZONA	JUGLANS MAJOR
519	WALNUT, BLACK	JUGLANS NIGRA
592	WALNUT, CALIFORNIA	JUGLANS CALIFORNICA
593	WALNUT, HINDS	JUGLANS HINDSII
741	WATERLOCUST	GLEDITSIA AQUATICA
527	WAXMYRTLE, PACIFIC	MYRICA SPP.
507	WILLOW, UNIDENTIFIED	SALIX SPP.
575	WILLOW, BLACK	SALIX NIGRA
748	WINTERBERRY, MOUNTAIN	ILEX MONTANA
694	WITCH-HAZEL	HAMAMELIS VIRGINIANA
554	YELLOW-POPLAR	LIRIODENDRON TULIPIFERA

Oak Species Codes

L = LIVE, W = WHITE, R-B = RED OR BLACK

800-899 OAKS
800 OAK, UNIDENTIFIED QUERCUS SPP.

824	BLACK, UNIDENT.	Q. SPP.		(R-B)
825	BLACK	Q. VELUTINA	NE, SE	(R-B)
821	BLACK	Q. COCCINEA	NE, SE	(R-B)
810	BLACK	Q. MARILANDICA	NE, SE	(R-B)
801	BLACK,CALIF.	Q. KELLOGGII	ORE.,CALIF.	(R-B)
810	BLACKJACK	Q. MARILANDICA	NE, SE	(R-B)
815	BLUE	Q. DOUGLASII	CALIF.	(W)
827	BLUEJACK	Q. INCANA	SE	
818	BUR	Q. MACROCARPA	NE, SE	(W)
801	CALIF. BLACK	Q. KELLOGGII	ORE.,CALIF.	(R-B)
817	CALIF. SCRUB	Q. DUMOSA	CALIF.	(W:L)
803	CALIF. WHITE	Q. LOBATA	CALIF.	(W)
812	CHERRYBARK	Q. FALCATA V PAGODAEFOLIA	NE, SE	(R-B)
828	CHESTNUT	Q. MICHAUXII	SE, TEXAS	
819	DURAND	Q. DURANDII	SE	(W)
829	EMORY	Q. EMORYI	SW	(R-B)
807	GAMBEL	Q. GAMBELII	NW, SW	(W)
806	GARRY	Q. GARRYANA	WASH.,ORE.,CALIF.	(W)

820	LIVE, UNIDENTIFIED - FROM CALIFORNIA OR FAR WEST			
814	LIVE (SE)	Q. VIRGINIANA	SE	(W:L)
802	LIVE,CALIF.	Q. AGRIFOLIA	CALIF.	(R-B:L)
804	LIVE,CANYON	Q. CHRYSOLEPIS	CALIF.,ORE.,NEV.	(W:L)
802	LIVE,COAST	Q. AGRIFOLIA	CALIF.	(R-B:L)
805	LIVE,HIGHLAND	Q. WISLIZENII	CALIF.	(R-B:L)
805	LIVE,INTERIOR	Q. WISLIZENII	CALIF.	(R-B:L)
814	LIVE,SCRUB	Q. VIRGINIANA	SE	(W:L)
817	LIVE,CAL.SCRUB	Q. DUMOSA	CALIF.	(W:L)
805	LIVE,SIERRA	Q. WISLIZENII	CALIF.	(R-B:L)
804	LIVE,WHITE	Q. CHRYSOLEPIS	CALIF.,ORE.,NEV.	(W:L)
804	MAUL	Q. CHRYSOLEPIS	TEX., OKLA.	(W:L)
813	MOHRS	Q. MOHRIANA	TEX.,OKLA.	(W)
815	MOUNTAIN WHITE	Q. DOUGLASII	CALIF.	(W)
823	NORTHERN RED	Q. RUBRA	NE, SE	(R-B)
806	OREGON WHITE	Q. GARRYANA	WASH,ORE,CALIF.	(W)
809	POST	Q. STELLATA	NE, SE	(W)
824	RED, UNIDENT.	Q. SPP.		(R-B)
821	RED	Q. COCCINEA	NE, SE	(R-B)
812	RED	Q. FALCATA V PAGODAEFOLIA	NE, SE	(R-B)
811	RED	Q. NIGRA	NE, SE	(R-B)
816	RED	Q. PHELLOS	NE, SE	(R-B)
823	RED,NORTHERN	Q. RUBRA	NE, SE	(R-B)
808	RED, SOUTHERN	Q. FALCATA V FALCATA	NE, SE	(R-B)
827	SANDJACK	Q. INCANA	SE	
821	SCARLET	Q. COCCINEA	NE, SE	(R-B)
813	SCRUB	Q. MOHRIANA	TEX.,OKLA.	(W)
817	SCRUB, CALIF	Q. DUMOSA	CALIF.	(W:L)
813	SHIN OAK	Q. MOHRIANA	TEX.,OKLA.	(W)
570	SILK-OAK	GREVILLEA ROBUSTA		(---)
808	SOUTHERN RED	Q. FALCATA V FALCATA	NE, SE	(R-B)
510	TANOAK	LITHOCARPUS DENSIFLORA		(---)
803	VALLEY	Q. LOBATA	CALIF.	(W)
811	WATER	Q. NIGRA	NE, SE	(R-B)
826	WHITE, UNIDENT.	Q. SPP.		(W)
822	WHITE	Q. ALBA	NE, SE	(W)
803	WHITE,CALIF.	Q. LOBATA	CALIF.	(W)
815	WHITE,MOUNTAIN	Q. DOUGLASII	CALIF.	(W)
806	WHITE, OREGON	Q. GARRYANA	WASH.,ORE.,CALIF.	(W)
807	WHITE,ROCKY MTN	Q. GAMBELII	NW, SW	(W)
816	WILLOW	Q. PHELLOS	NE, SE	(R-B)

Other Species Codes

950	PALM, UNIDENTIFIED	PALMAE
949	SAHUARO	CEREUS GIGANTEUS
999	GENUS UNKNOWN	(AVOID USE OF 999)

900-948 CODE NUMBERS FOR ADDITIONAL SPECIES.

951-998 CODE NUMBERS FOR ADDITIONAL SPECIES.

FOREST TYPE CODES AND DESCRIPTIONS

The codes listed represent a condensation of a forest type classification published by the Society of American Foresters (SAF)[2]. The code groupings are based on species composition of the stand, and frequency of the dominant and codominant trees. An effort has been made to retain broad ecological groupings in the condensation. Consequently, SAF classifications can be partially recreated in analyses by specifying appropriate limitations on species, altitude, and geographic location.

Modification of our forest type codes may be desirable when reports are being coded for areas limited to a given Forest Service Region or other agency. Any two-digit code may be added to or substituted for the one used here. For the most part, hardwood types are not separated in the following codes. However, note types 08, 09, 10, 11, 18, 19, and 20. For studies of hardwood hazard associated with local conditions, other hardwood types can be given code numbers between 22 and 98.

In the forest type descriptions, the numbers of the SAF cover types which fall within each type code are shown at the right. If actual percentage species composition is not given, species are described as predominant—the species makes up at least 50 percent of the stand, or pure—the species composes at least 80 percent of the stand. The forest type descriptions name the species that are frequent in the type, although others are normally present.

Codes

01	(PINE TYPE) (ALSO SEE LODGEPOLE)
02	(REDWOOD TYPE)
03	(DOUGLAS-FIR TYPE)
04	(FIR TYPE)
05	(MIXED CONIFER)
06	(LODGEPOLE PINE TYPE)
07	(JUNIPER - PINYON TYPE)
08	(CONIFER - HARDWOOD TYPE)
09	(HARDWOOD TYPE)
10	(WOODLAND - GRASS TYPE)
11	(CHAPARRAL - MESQUITE TYPE)
12	(GIANT SEQUOIA TYPE)
13	(SPRUCE TYPE)
14	(HEMLOCK TYPE)
15	(LARCH TYPE)
16	(CEDAR TYPE)
17	(EASTERN REDCEDAR TYPE)
18	(ASPEN TYPE)
19	(LANDSCAPE TYPE)
20	(STREAM TYPE)
21	(BALDCYPRESS-PONDCYPRESS TYPE)
22	(PALM TYPE)
23-98	(EXPANSION FOR FUTURE TYPES)
99	(UNIDENTIFIED)

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[2] Society of American Foresters. 1954, reprinted 1973. *Forest cover types of North America (exclusive of Mexico).* 67 p. Rep., Comm. Forest Types, Soc. Am. For., Washington, D.C.

Descriptions

01 (PINE TYPE)

PINES (PINUS SPP.) ARE PURE OR PREDOMINANT IN THE STAND. THIS TYPE DOES NOT INCLUDE COULTER, DIGGER, PINYON, LODGEPOLE, OR SUGAR PINE EXCEPT AS MINOR ASSOCIATES (SEE 08 CONIFER-HARDWOOD TYPE). SOME OF THE FOREST TYPES INCLUDED IN THIS GROUPING ARE:

WESTERN NORTH AMERICA

1) PONDEROSA PINE - INTERIOR AND PACIFIC	(TYPE 237, 245)
2) PONDEROSA PINE - DOUGLAS-FIR	(TYPE 244)
3) PONDEROSA PINE - LARCH - DOUGLAS-FIR	(TYPE 214)
4) JEFFREY PINE	(TYPE 247)
5) KNOBCONE PINE	(TYPE 248)
6) BRISTLECONE PINE	(TYPE 209)
7) WHITEBARK PINE	(TYPE 208)
8) WESTERN WHITE PINE	(TYPE 215)
9) LIMBER PINE	(TYPE 219)
10) MONTEREY PINE IN NATURAL ENVIRONMENT (RANGE)	

EASTERN NORTH AMERICA

1) JACK PINE	(TYPE 1,3,6,8)
2) RED PINE	(TYPE 15)
3) WHITE PINE	(TYPE 20,21,51)
4) WHITE PINE - HEMLOCK	(TYPE 22)
5) PITCH PINE	(TYPE 45)
6) SAND PINE	(TYPE 69)
7) LONGLEAF PINE	(TYPE 70,71,83)
8) SHORTLEAF PINE	(TYPE 75,76,77)
9) VIRGINIA PINE	(TYPE 78,79)
10) LOBLOLLY PINE	(TYPE 80,81,82)
11) SLASH PINE	(84,85,86,99)
12) POND PINE	(TYPE 98)

ASSOCIATE SPECIES

ASSOCIATES ARE NUMEROUS, INCLUDING OTHER CONIFEROUS SPECIES AND MANY HARDWOODS.

02 (REDWOOD TYPE) (TYPE 232)

REDWOOD (SEQUOIA SEMPERVIRENS) MAKES UP 20 PERCENT OR MORE OF THE STAND. GIANT SEQUOIA AND DAWN REDWOOD ARE NOT INCLUDED.

ASSOCIATE SPECIES

THE MOST COMMON ASSOCIATE OF REDWOOD IS DOUGLAS-FIR, WITH LESSER AMOUNTS OF GRAND FIR, WESTERN HEMLOCK, SITKA SPRUCE, PORT-ORFORD-CEDAR, PACIFIC YEW, WESTERN REDCEDAR, AND CALIFORNIA TORREYA. THE MOST IMPORTANT HARDWOODS ARE MADRONE AND TANOAK, WITH LESSER AMOUNTS OF CALIFORNIA LAUREL, OREGON WHITE OAK, PACIFIC WAXMYRTLE, AND OREGON ASH.

RANGE

COASTAL CALIFORNIA FROM SOUTHERN MONTEREY COUNTY NORTH TO THE OREGON - CALIFORNIA BORDER.

03 (DOUGLAS-FIR TYPE)

DOUGLAS-FIR IS PURE OR PREDOMINANT, INCLUDING BOTH THE PACIFIC COAST TYPE (VAR. MENZIESII) AND THE INTERIOR TYPE (VAR. GLAUCA). IN THE INTERIOR REGIONS, DOUGLAS-FIR AND WHITE FIR TOGETHER MAY PREDOMINATE. BIG CONE DOUGLAS-FIR (PSEUDOTSUGA MACROCARPA) IS NOT INCLUDED IN THIS TYPE. THE FOLLOWING ARE INCLUDED IN THIS GROUPING.

1) PACIFIC DOUGLAS-FIR	(TYPE 229)
2) INTERIOR DOUGLAS-FIR	(TYPE 210)
3) DOUGLAS-FIR - WESTERN HEMLOCK	(TYPE 230)
4) PORT-ORFORD-CEDAR - DOUGLAS-FIR	(TYPE 231)

ASSOCIATE SPECIES

ALONG THE PACIFIC COAST - REDWOOD, PORT-ORFORD-CEDAR, PONDEROSA PINE, WESTERN WHITE PINE, WESTERN HEMLOCK, GRAND FIR, WESTERN REDCEDAR, PACIFIC SILVER FIR, NOBLE FIR, SITKA SPRUCE, AND INCENSE CEDAR. HARDWOOD ASSOCIATES ARE MADRONE, TANOAK, YEW, CALIFORNIA LAUREL, AND OTHER COASTAL SPECIES. INTERIOR ASSOCIATES ARE WHITE FIR, WESTERN LARCH, GRAND FIR, WESTERN WHITE PINE, PONDEROSA PINE, LODGEPOLE PINE, BLUE SPRUCE, LIMBER PINE, AND ASPEN.

04 (FIR TYPE)

1) WHITE FIR (TYPE 211)

WHITE FIR IS PURE OR PREDOMINANT.

ASSOCIATE SPECIES

DOUGLAS-FIR, PONDEROSA PINE, SUGAR PINE, JEFFREY PINE, LODGEPOLE PINE, WESTERN WHITE PINE, RED FIR, AND OTHER TRUE FIRS.

RANGE

SOUTHERN CASCADE MOUNTAIN RANGE AND RANGES IMMEDIATELY TO THE EAST IN OREGON AND CALIFORNIA. DOES NOT OCCUR AS A TRUE FIR TYPE IN THE INTERIOR REGIONS.

2) RED FIR (TYPE 207)

RED FIR IS PURE OR PREDOMINANT

ASSOCIATE SPECIES

JEFFREY PINE, WESTERN WHITE PINE, LODGEPOLE PINE, AND MOUNTAIN HEMLOCK AT HIGHER ELEVATIONS. LOWER ELEVATION ASSOCIATES ARE SUGAR PINE AND WHITE FIR. OTHER ASSOCIATES ARE NOBLE FIR, WHITEBARK PINE, INCENSE CEDAR, AND DOUGLAS-FIR.

RANGE

HIGH ELEVATIONS EXTENDING FROM THE SOUTHERN SIERRA NEVADA MOUNTAINS OF CALIFORNIA INTO THE SOUTHERN CASCADES IN OREGON.

3) PACIFIC SILVER FIR (TYPE 226)

PACIFIC SILVER FIR IS PREDOMINANT.

ASSOCIATE SPECIES

WESTERN HEMLOCK, MOUNTAIN HEMLOCK, DOUGLAS-FIR, WESTERN REDCEDAR, NOBLE FIR, GRAND FIR, ALASKA-CEDAR, AND WESTERN WHITE PINE.

RANGE

SOUTHERN ALASKA TO SOUTHERN OREGON.

4) GRAND FIR (TYPE 213)

GRAND FIR, LARCH AND DOUGLAS-FIR TOGETHER PREDOMINATE

ASSOCIATE SPECIES

LARCH, DOUGLAS-FIR, WESTERN HEMLOCK, WESTERN WHITE PINE, PONDEROSA PINE, AND ENGELMANN SPRUCE.

RANGE

NORTHERN WASHINGTON, IDAHO, MONTANA, AND OREGON.

5) BALSAM FIR (TYPE 5)

BALSAM FIR IS PURE OR PREDOMINANT.

ASSOCIATE SPECIES

BLACK SPRUCE, WHITE SPRUCE, RED SPRUCE, PAPER BIRCH AND ASPEN.

RANGE

NORTHEASTERN AND LAKE STATES.

05 (MIXED CONIFER) (TYPE 243)

PONDEROSA PINE, SUGAR PINE, AND WHITE FIR PREDOMINATE.

ASSOCIATE SPECIES

DOUGLAS-FIR, INCENSE CEDAR, JEFFREY PINE, RED FIR, AND BLACK OAK.

RANGE

TYPICAL OF ELEVATIONS FROM 3,000 TO 6,000 FEET IN THE SIERRA NEVADA - EXTENDING FROM SOUTHERN OREGON, SOUTH TO THE MOUNTAINS OF SOUTHERN CALIFORNIA, AND WEST INTO THE COAST RANGES.

06 (LODGEPOLE PINE TYPE) (TYPE 218)

LODGEPOLE PINE IS PURE OR PREDOMINANT.

ASSOCIATE SPECIES

WESTERN WHITE PINE, PONDEROSA PINE, DOUGLAS-FIR, GRAND FIR, SUBALPINE FIR, ENGELMANN SPRUCE, WESTERN LARCH, ASPEN, AND MOUNTAIN HEMLOCK.
(WHITE FIR, JEFFREY PINE, RED FIR, COTTONWOOD IN TAHOE REGION).

RANGE

SOUTHERN ALASKA SOUTH. MOST WIDELY DEVELOPED IN SOUTHERN MONTANA, NORTHERN WYOMING, CENTRAL COLORADO AND UTAH, SOUTHERN IDAHO, IN CASCADE AND SIERRA NEVADA RANGES, AND ALONG THE PACIFIC COAST.

07 (JUNIPER - PINYON TYPE) (TYPE 66,220, 238,239,240)

JUNIPER OR PINYON PREDOMINATE TOGETHER OR SINGLY.

ASSOCIATE SPECIES

PONDEROSA PINE, ARIZONA CYPRESS, JEFFREY PINE, SEVERAL SCRUB OAKS, AND ASPEN

RANGE

EASTERN AND CENTRAL OREGON, SOUTHERN COLORADO AND NEW MEXICO, WESTERN UTAH, NEVADA, ARIZONA, TEXAS AND CALIFORNIA.

08 (CONIFER - HARDWOOD TYPE) (TYPE 250)

A GENERAL TYPE IN WHICH BOTH HARDWOODS AND CONIFERS OCCUR IN MIXTURE. IN CALIFORNIA IT INCLUDES DIGGER PINE (TYPE 250), COULTER PINE, AND BRISTLECONE FIR WITH SEVERAL OTHER CONIFERS OCCURRING IN MIXTURE. IN THE EASTERN UNITED STATES IT INCLUDES THE PINE-HARDWOODS TYPES, PROVIDED NEITHER PINES NOR HARDWOODS PREDOMINATE INDIVIDUALLY. USE MORE SPECIFIC TYPE DESIGNATION WHEN POSSIBLE.

09 (HARDWOOD TYPE)

HARDWOODS PREDOMINATE IN THE STAND. THIS IS A GENERAL CLASSIFICATION WHICH INCLUDES NEARLY ALL DOMINANT HARDWOOD TYPES. THERE SHOULD NOT BE MANY CONIFER SPECIES PRESENT (SEE CONIFER-HARDWOOD), AND THE STAND SHOULD NOT BE OPEN (SEE WOODLAND-GRASS). NEITHER DOES THE TYPE FALL WITHIN STREAM TYPE, LANDSCAPE TYPE, ASPEN TYPE OR CHAPARRAL TYPE CATEGORIES.

10 (WOODLAND-GRASS TYPE)

AREAS OF PRIMARILY HARDWOODS WITH SOME CONIFERS IN A VERY OPEN STAND INTERSPERSED WITH OPEN GRASSY AREAS. THIS TYPE IS COMMON IN THE COASTAL MOUNTAINS AND SIERRA NEVADA FOOTHILLS OF CALIFORNIA, BUT IS COUNTRYWIDE IN OCCURRENCE.

11 (CHAPARRAL - MESQUITE - CHAMISAL TYPE) (TYPE 68,242)

DENSE STAND OF BROADLEAVED BRUSH OR SHRUB TREE SPECIES OF FROM 5 TO 25 FEET TALL. INCLUDES MESQUITE AND SCRUB OAKS. THIS TYPE IS TYPICAL OF POOR SITES AND ARID REGIONS OF THE WEST. LARGER TREE SPECIES MAY BE INTERSPERSED IN CHAPARRAL BUT DO NOT PREDOMINATE.

12 (GIANT SEQUOIA TYPE)

GIANT SEQUOIA IS PRESENT. ALSO SEE MIXED CONIFER TYPE.

ASSOCIATE SPECIES

MOST TREES OF THE MIXED CONIFER TYPE.

RANGE

SCATTERED SMALL AREAS IN THE CENTRAL SIERRA NEVADA MOUNTAINS OF CALIFORNIA.

13 (SPRUCE TYPE)

1) ENGELMANN SPRUCE - SUBALPINE FIR (TYPE 206)

EITHER ENGELMANN SPRUCE OR SUBALPINE FIR OR A MIXTURE OF THE TWO IS PURE OR PREDOMINANT.

ASSOCIATE SPECIES

DOUGLAS-FIR, GRAND FIR, WHITEBARK PINE, LODGEPOLE PINE, WESTERN LARCH, WESTERN HEMLOCK, WESTERN REDCEDAR, WESTERN WHITE SPRUCE, LIMBER PINE, AND ASPEN.

RANGE

CASCADE MOUNTAINS IN OREGON, AND THE ROCKY MOUNTAINS FROM ARIZONA AND NEW MEXICO NORTH TO CANADA.

2) SITKA SPRUCE (TYPE 223)

SITKA SPRUCE IS PURE (MORE THAN 80 PERCENT OF STAND)

ASSOCIATE SPECIES

WESTERN HEMLOCK, DOUGLAS-FIR, PACIFIC SILVER FIR, WESTERN REDCEDAR, PORT-ORFORD-CEDAR, AND RED ALDER.

RANGE

COASTAL AREAS FROM ALASKA SOUTH TO NORTHERN CALIFORNIA.

3) BLUE SPRUCE (TYPE 216)

BLUE SPRUCE IS PURE OR PREDOMINANT.

ASSOCIATE SPECIES

DOUGLAS-FIR, WHITE FIR, ENGELMANN SPRUCE, PONDEROSA PINE, AND SEVERAL HARDWOODS.

RANGE

MOUNTAINS OF WYOMING, UTAH, COLORADO, NEW MEXICO, AND PARTS OF ARIZONA.

4) BLACK SPRUCE (TYPE 2,7,10,12, 13,204)

BLACK SPRUCE IS PURE OR PREDOMINANT.

ASSOCIATE SPECIES

TAMARACK, BALSAM FIR, AND PAPER BIRCH.

RANGE

ALASKA TO THE LAKE STATES AND NEW ENGLAND.

5) WHITE SPRUCE (TYPE 4,9,36, 201,202)

WHITE SPRUCE IS PURE OR PREDOMINANT.

ASSOCIATE SPECIES

BIRCH, ASPEN, BALSAM POPLAR, AND BALSAM FIR.

RANGE

ALASKA SOUTHEAST TO THE GREAT LAKES AND NORTHEASTERN UNITED STATES.

6) SITKA SPRUCE - WESTERN HEMLOCK (TYPE 225)

EITHER SPECIES MAY PREDOMINATE.

ASSOCIATE SPECIES

DOUGLAS-FIR, WESTERN REDCEDAR, AND RED ALDER.

RANGE

KENAI PENNISULA, ALASKA, SOUTH ALONG THE COAST TO SOUTHERN OREGON. MAY EXTEND INLAND 50 MILES.

7) RED SPRUCE (TYPE 30,31,32, 33,34)

ASSOCIATE SPECIES

YELLOW BIRCH, PAPER BIRCH, SUGAR MAPLE, BEECH, BALSAM FIR, FRASER FIR.

RANGE

NORTHERN NEW ENGLAND AND NEW YORK, PENNSYLVANIA AND APPALACHIANS.

14 (HEMLOCK TYPE)

1) MOUNTAIN HEMLOCK - SUBALPINE FIR (TYPE 205)

MOUNTAIN HEMLOCK AND SUBALPINE FIR TOGETHER PREDOMINATE.

ASSOCIATE SPECIES

ENGELMANN SPRUCE, PACIFIC SILVER FIR, NOBLE FIR, WESTERN LARCH, SUBALPINE LARCH, WHITEBARK PINE, WESTERN HEMLOCK, AND IN ALASKA, SITKA SPRUCE, ALASKA-CEDAR, AND LODGEPOLE PINE.

RANGE

FROM CASCADE MOUNTAINS IN SOUTHERN OREGON NORTH ALONG THE COAST INTO ALASKA.

2) **WESTERN HEMLOCK** (TYPE 224)

WESTERN HEMLOCK IS PURE (80 PERCENT OR MORE OF STAND)

ASSOCIATE SPECIES

SITKA SPRUCE, WESTERN REDCEDAR, AND DOUGLAS-FIR ALONG THE COAST, FURTHER INLAND, ALASKA-CEDAR, GRAND FIR, PACIFIC SILVER FIR, NOBLE FIR, SUBALPINE FIR, MOUNTAIN HEMLOCK, AND WESTERN WHITE PINE.

RANGE

SOUTHERN ALASKA, WESTERN WASHINGTON, OREGON, AND NORTHERN IDAHO.

3) **EASTERN HEMLOCK** (TYPE 23,24)

EASTERN HEMLOCK IS PURE OR PREDOMINANT.

ASSOCIATE SPECIES

YELLOW BIRCH AND OTHER HARDWOODS.

RANGE

LAKE STATES TO EAST COAST.

15 (LARCH TYPE)

1) **WESTERN LARCH** (LARIX OCCIDENTALIS) (TYPE 212)

WESTERN LARCH IS PREDOMINANT.

ASSOCIATE SPECIES

MOST COMMONLY ASSOCIATES WITH DOUGLAS-FIR, LESS COMMON WITH LODGEPOLE PINE, GRAND FIR, WESTERN WHITE PINE, PONDEROSA PINE, WESTERN REDCEDAR, AND ENGELMANN SPRUCE.

RANGE

NORTHERN WASHINGTON, IDAHO, AND MONTANA.

2) **TAMARACK** (LARIX LARICINA) (TYPE 38)

TAMARACK IS PURE OR PREDOMINANT.

ASSOCIATE SPECIES

BLACK SPRUCE, WHITE SPRUCE, BALSAM FIR, NORTHERN WHITE-CEDAR, JACK PINE, BALSAM POPLAR, AND MANY HARDWOODS.

RANGE

EASTERN UNITED STATES TO THE LAKE STATES.

16 (CEDAR TYPE)

1) WESTERN REDCEDAR OR ALASKA-CEDAR (TYPE 227,228)

OCCUR SINGLY AS A PURE STAND OR TOGETHER MAKE UP 80 PERCENT OF A STAND. THIS TYPE DOES NOT INCLUDE PORT-ORFORD-CEDAR OR INCENSE-CEDAR.

ASSOCIATE SPECIES

WESTERN HEMLOCK, WESTERN WHITE PINE, ENGELMANN SPRUCE, AND GRAND FIR IN THE NORTHERN ROCKY MOUNTAINS. WEST OF THE CASCADE RANGE ASSOCIATES ARE DOUGLAS-FIR, WESTERN HEMLOCK, SITKA SPRUCE, AND GRAND FIR.

RANGE

NORTHERN IDAHO, WESTERN MONTANA, EASTERN WASHINGTON, AND ALONG THE COAST FROM ALASKA TO SOUTHERN OREGON.

2) ATLANTIC WHITE-CEDAR (TYPE 97)

ATLANTIC WHITE-CEDAR CHARACTERISTICALLY PURE OR PREDOMINANT.

ASSOCIATE SPECIES

RED MAPLE, GRAY BIRCH, PITCH PINE AND POND PINE.

RANGE

EAST COAST.

3) NORTHERN WHITE-CEDAR (TYPE 37)

NORTHERN WHITE-CEDAR IS PURE OR PREDOMINATES.

ASSOCIATE SPECIES

BALSAM FIR, TAMARACK, AND YELLOW BIRCH.

RANGE

LAKE STATES AND NORTHEASTERN UNITED STATES.

17 (EASTERN REDCEDAR TYPE)

1) EASTERN REDCEDAR (TYPE 46)

EASTERN REDCEDAR IS PURE OR PREDOMINANT.

ASSOCIATE SPECIES

IN THE NORTHEAST GRAY BIRCH, RED MAPLE, SWEET BIRCH, QUAKING AND BIGTOOTH ASPEN, IN THE OZARKS THEY ARE BLACKJACK OAK, POST OAK, AND SHORTLEAF PINE

RANGE

SCATTERED THROUGH OUT THE CENTRAL FOREST AND NORTHERN PORTIONS OF THE SOUTHERN FOREST.

2) EASTERN REDCEDAR - PINE (TYPE 47)

EASTERN REDCEDAR AND EITHER SHORTLEAF OR VIRGINIA PINE PREDOMINATE.

ASSOCIATE SPECIES

POST OAK, CHESTNUT OAK, RED OAK, RED MAPLE, AND DOGWOOD.

RANGE

SOUTHERN CENTRAL FOREST EXTENDING INTO THE NORTHERN SOUTHERN FOREST.

3) EASTERN REDCEDAR - HARDWOOD (TYPE 48,49)

EASTERN REDCEDAR AND SEVERAL HARDWOODS INCLUDING RED AND WHITE OAKS, HICKORIES, AND BLACK WALNUT PREDOMINATE.

ASSOCIATE SPECIES

SHORTLEAF, LOBLOLLY AND VIRGINIA PINE, HACKBERRY, ASH, WINGED ELM, BLACK LOCUST, DOGWOOD, BLACKGUM, AND OTHER HARDWOODS.

RANGE

SCATTERED THROUGH THE CENTRAL FOREST AND SOUTH TO MID-ALABAMA, MISSISSIPPI AND NORTHERN ARKANSAS.

18 (ASPEN TYPE) (TYPE 11,16,217)

ASPEN (POPULUS TREMULOIDES) PURE OR PREDOMINANT. IF ASPEN CONSTITUTES LESS THAN 50 PERCENT OF THE STAND, IT IS CONSIDERED AN ASSOCIATE SPECIES WITHIN SOME OTHER FOREST TYPE, AS E.G., 06, 13, 01, 03, 07.

19 (LANDSCAPE TYPE)

TREES USUALLY PLANTED FOR AESTHETIC PURPOSE. CHARACTERISTICALLY OPEN AS IN WOODLAND GRASS TYPE AND PREDOMINANTLY, BUT NOT ALWAYS, HARDWOOD ORIENTED. MAY BE EITHER EXOTIC OR NATIVE SPECIES.

20 (STREAM TYPE)

RATHER NARROW BAND OF TREES USUALLY FOUND ALONG A NARROW WATERWAY. CHARACTERISTICALLY OCCURS AT HIGHER ALTITUDES. USUALLY HARDWOOD SPECIES AND USUALLY DIFFERENT FROM SURROUNDING FOREST TYPE. ALSO CALLED RIPARIAN TYPE.

21 (BALDCYPRESS-PONDCYPRESS TYPE) (TYPE 100,101, 102)

ONE SPECIES IS USUALLY PREDOMINANT OR PURE. ASSOCIATE SPECIES MAY INCLUDE TUPELO, BLACKGUM AND OTHER HARDWOODS. FOUND ON SOUTHERN FOREST FLOOD PLAINS AND SWAMPS.

22 (PALM TYPE)

ESPECIALLY REFERS TO UPPER LUQUILLO FOREST OF PUERTO RICO WHERE SIERRA PALM IS VERY COMMON. BY EXTENSION, OTHER PALM FORESTS IF NOT FURTHER IDENTIFIED.

Associates of Softwoods by Species and Location

The following list is intended as an aid to locating or confirming the appropriate forest type code. In this list, applicable type code numbers are given by tree species and location. Species subgroupings, as defined in the preceding forest type descriptions, are shown in parentheses. Symbols for species and location are used for brevity, according to the keys which follow the list. Starred species are a major component of the type for the given location.

```
CEDAR FAMILY
----- ------

    ALASKA-CEDAR
          PNW -- 04 (PSF), 14 (WH), 16 (WRC)

    EASTERN REDCEDAR
          SE --- 17 (ERC*)
          CE --- 17 (ERC*)

    INCENSE CEDAR
          PNW -- 03 (PDF)
          NC --- 01 (PPP), 03 (PDF)
          SC --- 01 (JP), 05 (MC)
          SN --- 01 (JP, PP-DF, PPP), 05 (MC)


    PORT-ORFORD-CEDAR
          PNW -- 03 (POC-DF*, PDF), 13 (SS)
          NC --- 03 (POC-DF*, PDF), 13 (SS)

    WESTERN-REDCEDAR
          PNW -- 03 (DF-WH, POC-DF, PDF), 04 (PSF), 14 (WH), 16 (WRC*)
          NC --- 02 (RW), 03 (POC-DF, PDF)
          NRM -- 01 (WWP), 13 (ES-SF, SS), 15 (WL), 16 (WRC*)


DOUGLAS-FIR
-----------

    DOUGLAS-FIR
          PNW -- 01 (KP, PPP), 03 (PDF*, DF-WH*, POC-DF*), 04 (GF, PSF), 06 (LP)
                 13 (SS), 14 (WH), 16 (WRC)
          NC --- 01 (KP, PPP), 02 (RW), 03 (PDF*, POC-DF*)
          SC --- 01 (KP), 05 (MC)
          SN --- 01 (PP-DF*, PPP), 04 (WF), 05 (MC), 06 (LP)
          NRM -- 01 (PP-L-DF, WWP), 03 (IDF), 04 (GF), 06 (LP), 13 (ES-SF),
                 14 (WH), 15 (WL)
          CRM -- 01 (IPP), 03 (IDF*), 06 (LP), 13 (ES-SF, BS)
          SRM -- 01 (IPP), 03 (IDF*), 13 (ES-SF, BS)

    BIG-CONE DOUGLAS-FIR
          SC --- 01 (JP), 08


FIR
---

    BRISTLECONE
          SC --- 08
    GRAND
         PNW -- 02 (RW), 03 (PDF, POC-DF), 04 (GF*, PSF, WF)
         NRM -- 01 (WWP), 03 (IDF), 04 (GF*), 06 (LP), 13 (ES-SF), 14 (WH),
                15 (WL), 16 (WRC)

    NOBLE
         PNW -- 03 (PDF, DF-WH), 04 (PSF), 14 (MH-SF, WH)

    PACIFIC SILVER
         PNW -- 03 (PDF), 04 (PSF*), 13 (SS), 14 (WH, MH-SF)

    RED
         SN --- 01 (JP, WBP), 04 (RF*), 05 (MC)

    SUBALPINE
         PNW -- 01 (WBP), 04 (PSF), 06 (LP), 14 (MH-SF*, WH)
         NRM -- 01 (WBP), 03 (IDF), 06 (LP), 13 (ES-SF*), 14 (WH)
         CRM -- 01 (BP), 03 (IDF), 06 (LP), 13 (ES-SF*)
         SRM -- 01 (WBP), 03 (IDF), 13 (ES-SF*)

    WHITE
         NC --- 03 (PDF)
         SC --- 01 (JP), 05 (MC)
         SN --- 01 (JP, PP-DF, PPP), 04 (WF*, RF), 05 (MC)
         CRM -- 01 (IPP), 03 (IDF), 13 (BS)
         SRM -- 01 (IPP), 03 (IDF), 13 (BS)

HEMLOCK
-------

    MOUNTAIN HEMLOCK
         PNW -- 01 (WBP), 04 (PSF), 14 (MH-SF*, WH), 06 (LP)
         SN --- 01 (JP), 04 (RF)
         NRM -- 13 (ES-SF)

    WESTERN HEMLOCK
         PNW -- 01 (WWP), 02 (RW), 03 (PDF, PDF-WH, POC-DF), 04 (PSF), 13 (SS),
                14 (WH*, MH-SF), 16 (WRC)
         NRM -- 01 (WWP), 13 (ES-SF), 14 (WH*), 16 (WRC)

LARCH
-----

    SUBALPINE
         PNW -- 01 (WBP), 14 (MH-SF)
         NRM -- 01 (WBP)

    TAMARACK
         NE --- 15 (T*)

    WESTERN LARCH
         PNW -- 03 (DF-WH), 14 (MH-SF)
         NRM -- 01 (IPP, WWP, PP-L-DF), 03 (IDF), 13 (ES-SF), 15 (WL*)

PINE
----

    APACHE
         SRM -- 01

    BISHOP
         NC --- 01
         SC --- 01

    BRISTLECONE
         CRM -- 01 (BP*, LMP)
```

```
CHIHUAHUA
     SRM -- 01

COULTER
     SC --- 01 (KP), 08

DIGGER
     NC --- 08
     SC --- 08
     SN --- 08

FOXTAIL
     SN --- 01 (WBP*)

JEFFREY
     SC --- 01 (JP*)
     SN --- 01 (JP*, PP-DF), 04 (RF), 05 (MC), 07 (J-P)

KNOBCONE
     PNW -- 01 (KP*), 03 (POC-DF)
     NC --- 01 (KP*), 03 (POC-DF)

LIMBER
     NRM -- 01 (LMP*, WBP), 13 (ES-SF)
     CRM -- 01 (LMP*, BP, IPP), 03 (IDF), 13 (ES-SF)
     SRM -- 01 (LMP*, PP), 03 (IDF), 13 (ES-SF)

LOBLOLLY
     SE --- 01, 08


LODGEPOLE
     PNW -- 01 (WBP), 06 (LP*)
     SN --- 01 (JP, WBP), 04 (WF, RF), 06 (LP*), 13 (ES-SF)
     NRM -- 01 (WBP, WWP, PP-L-DF), 03 (IDF), 06 (LP*), 07 (J-P), 13 (ES-SF)
            15 (WL)
     CRM -- 03 (IDF), 06 (LP*), 07 (J-P), 13 (ES-SF)

LONGLEAF
     SE --- 01, 08


MONTEREY
     SC --- 01

PINYON
     SC --- 07 (J-P)
     CRM -- 07 (J-P)
     SRM -- 07 (J-P)

PITCH
     NE --- 01, 08
     CE --- 01, 08

PONDEROSA
     PNW -- 01 (KP), 04 (GF), 06 (LP)
     NC --- 01 (KP)
     SN --- 01 (PP-DF*, JP), 04 (WF), 05 (MC), 06 (LP), 07 (J-P)
     NRM -- 01 (PP-L-DF*, LMP, WWP), 03 (IDF), 04 GF), 06 (LP), 07 (J-P),
            15 (WL)
     SRM -- 01 (IPP*, LMP), 03 (IDF), 07 (J-P), 13 (BS)
     CRM -- 01 (IPP*, LMP, BP), 03 (IDF), 06 (LP), 07 (J-P), 13 (BS)

SHORTLEAF
     CE --- 01, 08, 17 (ERC)
     SE --- 01, 08
```

```
    SUGAR
         PNW -- 01 (PP-DF, PPP), 03 (POC-DF)
         NC --- 01 (PP-DF, PPP), 03 (POC-DF)
         SN --- 01 (PP-DF, PP), 04 (RF, WF), 05 (MC)

    TORREY
         SC --- 01

    WASHOE
         SN --- 01 (JP)

    WESTERN WHITE
         PNW -- 03 (PDF, DF-WH, POC-DF), 04 (GF, PSF), 06 (LP), 14 (WH),
                16 (WRC)
         SN --- 01 (JP), 04 (RF)
         NRM -- 01 (WWP*, IPP, PP-L-DF), 03 (IDF), 04 (GF), 06 (LP), 13 (ES-SF),
                14 (WH), 15 (WL), 16 (WRC)
    WHITEBARK
         PNW -- 01 (WBP*), 14 (MH-SF)
         SN --- 01 (WBP*, JP), 04 (RF)
         NRM -- 01 (WBP*, LMP), 13 (ES-SF)


SEQUOIA
-------

    COAST REDWOOD
         NC --- 02 (RW*), 03 (PDF, POC-DF)

    GIANT SEQUOIA
         SN --- 12*

SPRUCE
------

    BLACK
         NE --- 13 (BLKS*, WS), 15 (T)

    BLUE
         CRM -- 03 (IDF), 13 (BS*)
         SRM -- 03 (IDF), 13 (BS*)

    BREWER
         NC --- 14

    ENGELMANN
         PNW -- 04 (PSF), 14 (MH-SF)
         NRM -- 01 (WBP), 03 (IDF), 06 (LP), 13 (ES-SF*), 15 (WL)
         CRM -- 01 (BP), 03 (IDF), 06 (LP), 13 (ES-SF*, BS)
         SRM -- 01 (WBP), 03 (IDF), 13 (ES-SF*, BS)

    SITKA
         PNW -- 03 (PDF, PDF-WH, POC-DF), 13 (SS*), 14 (MH-SF, WH), 16 (WRC)
         NC --- 02 (RW), 03 (PDF), 13 (SS*)

    WHITE
         NE --- 01, 13 (WS*)

YEW
---

    PACIFIC YEW
         PNW -- 03 (PDF)
         NC --- 03 (PDF)
         SN --- 01 (PP-DF)
```

SPECIES SYMBOLS

BLKS	BLACK SPRUCE
BP	BRISTLECONE PINE
BS	BLUE SPRUCE
DF-WH	DOUGLAS-FIR - WESTERN HEMLOCK
ERC	EASTERN REDCEDAR
ES-SF	ENGELMANN SPRUCE - SUBALPINE FIR
GF	GRAND FIR
IDF	INTERIOR DOUGLAS-FIR
IPP	INTERIOR PONDEROSA PINE
J-P	JUNIPER - PINYON
JP	JEFFREY PINE
KP	KNOBCONE PINE
LMP	LIMBER PINE
LP	LODGEPOLE PINE
MC	MIXED CONIFER
MH-SF	MOUNTAIN HEMLOCK - SUBALPINE FIR
PDF	PACIFIC DOUGLAS-FIR
POC-DF	PORT-ORFORD-CEDAR - DOUGLAS-FIR
PP-DF	PONDEROSA PINE - DOUGLAS-FIR
PP-L-DF	PONDEROSA PINE - LARCH - DOUGLAS-FIR
PPP	PACIFIC PONDEROSA PINE
PSF	PACIFIC SILVER FIR
RF	RED FIR
RW	REDWOOD
SS	SITKA SPRUCE
T	TAMARACK
WBP	WHITEBARK PINE
WF	WHITE FIR
WH	WESTERN HEMLOCK
WL	WESTERN LARCH
WRC	WESTERN RED CEDAR
WS	WHITE SPRUCE
WWP	WESTERN WHITE PINE

LOCATION SYMBOLS

WESTERN NORTH AMERICA

PACIFIC NORTHWEST (PNW)

WESTERN HALF OF OREGON AND WASHINGTON EXTENDING FROM THE PACIFIC COAST TO THE WESTERN BOUNDARIES OF KLAMATH, DESCHUTES, JEFFERSON, AND WASCO COUNTIES IN OREGON, AND THE WESTERN BOUNDARIES OF BENTON, GRANT AND PERRY COUNTIES OF WASHINGTON.

NORTHERN CALIFORNIA (NC)

COASTAL MOUNTAINS FROM THE OREGON BORDER SOUTH TO SAN FRANCISCO BAY.

SOUTHERN CALIFORNIA (SC)

COASTAL MOUNTAINS FROM SAN FRANCISCO BAY SOUTH TO THE MEXICO BORDER.

SIERRA NEVADA (SN)

SIERRA NEVADA MOUNTAINS OF CALIFORNIA FROM THE CALIFORNIA-OREGON BORDER SOUTH TO THE SOUTHERN BORDER OF KERN COUNTY. THIS REGION IS BOUNDED BY THE CENTRAL VALLEY ON THE WEST AND THE CALIFORNIA-NEVADA BORDER IN THE EAST.

NORTHERN ROCKY MOUNTAINS (NRM)

EASTERN HALF OF OREGON AND WASHINGTON (EASTERN BOUNDARY OF PNW), AND ALSO STATES OF IDAHO, MONTANA AND WYOMING.

CENTRAL ROCKY MOUNTAINS (CRM)

NEVADA, UTAH AND COLORADO.

SOUTHERN ROCKY MOUNTAINS (SRM)

NEW MEXICO, ARIZONA AND THE SOUTHWESTERN PORTION OF CALIFORNIA (TO THE COASTAL MOUNTAINS IN THE WEST AND THE SIERRA NEVADA MOUNTAINS IN THE NORTH).

EASTERN NORTH AMERICA

FOR A MORE COMPLETE DESCRIPTION OF THE EASTERN FOREST REGIONS SEE THE MAP IN THE SAF 'FOREST COVER TYPES OF NORTH AMERICA' AND SUBSEQUENT TYPE DESCRIPTIONS.

NORTH EASTERN FOREST (NE)

MAINE, NEW HAMPSHIRE, VERMONT, NEW YORK, AND THE NORTHERN PORTIONS OF MINNESOTA, WISCONSIN, MICHIGAN, PENNSYLVANIA AND MASSACHUSETTS.

CENTRAL EASTERN FOREST (CE)

ILLINOIS, INDIANA, OHIO, MISSOURI, KENTUCKY AND TENNESSEE.

SOUTH EASTERN FOREST (SE)

NORTH CAROLINA, SOUTH CAROLINA, GEORGIA, ALABAMA, MISSISSIPPI, ARKANSAS, LOUISIANA, FLORIDA, AND PARTS OF TEXAS AND VIRGINIA.

AGENCY CODES – OUTLINE

Codes have been assigned to agencies and their individual units to permit recall and analysis of information according to agency or unit. The fields 44-48 and 50-51 in the card 1 format are used for this purpose. In general, as shown earlier in the description of card formats, the parent agency is identified by the first two digits, the next subdivision by the third digit, and the following two levels by two digits each in columns 47-48 and 50-51.

In the outline of codes, which is arranged in alphabetic order, the two-digit codes for the agency are shown, followed by zeros. (In a few cases, three digits are used.) The subunit codes are given in the detailed listing which follows the outline, to the extent that specific codes have been assigned. The detailed listing is given in approximate numerical order of codes, so that a particular agency can be located by the general code shown in the outline.

New numbers should be assigned to agency units as they change boundaries, and old numbers should be permanently retired to avoid confusion.

Unique State agency codes are not required for most States because the State identity is separately established in the card format. Thus, when data of a given organization in a given State are to be analyzed (using the FAILURE program), selection is made first for State, and then for Agency.

To code an agency in a State for which the State agencies are not listed in this outline,

1. Use the general code number assigned to the parallel agency in California, if any. In particular, use 52000 00 for the Department of Parks and Recreation of any State. Do not use 52000 00 for any agency other than Parks and Recreation, or for any level lower than State.

2. If no parallel agency has been assigned a code in California, use the 58000 00 series. Appropriate code numbers for the agency and subunits may be assigned as needed, following the general plan—for example, 58101 01 might designate a State agency and subunit in Massachusetts for which there is no parallel in California.

State Parks of some participating States are individually named and numbered in the code (for example, see California State Parks codes). Again, parks in two or more States may have the same code but are always separable by the State code.

It should be noted that for Regional, County, or City organizations, or for Private Property (70000 00), the functional designation is shown in the third column of the field (column 46 on data card 1) using codes shown in the footnote. City identity is defined in the last four columns (47-48 and 50-51) using the GSA *Worldwide Geographic Location Codes* (U.S. General Services Administration, Office of Finance, 1976, 381 p.). The County is already defined in the State and County coding field, and should not be repeated. Regional character of an agency subunit is shown by the code 1 in column 52. Additional functional codes may be added as needed, as illustrated by the examples in the footnote. In conjunction with the State, County, and City codes, these agency codes will permit selection of data for listing or for analysis from the computer data file for any individual public agency below the State level.

AGENCIES	CODES
AGRICULTURE, U.S. DEPT OF	
FOREST SERVICE	01000 00
OFFICE OF THE GENERAL COUNSEL	75000 00
SOIL CONSERVATION SERVICE	77000 00
CORPS OF ENGINEERS (U.S. DEPT OF DEFENSE)	42000 00
INDIAN TRIBAL LANDS	03000 00
INTERIOR, U.S. DEPT OF	
INDIAN AFFAIRS, BUREAU OF	03000 00
LAND MANAGEMENT, BUREAU OF	41000 00
NATIONAL PARK SERVICE	02000 00
OUTDOOR RECREATION, BUREAU OF	73000 00
RECLAMATION, BUREAU OF	80000 00
REGIONAL SOLICITOR	02000 002
FISH AND WILDLIFE SERVICE	04000 00

AGENCIES	CODES
NATIONAL SAFETY COUNCIL	74000 00
PRIVATE PROPERTY	70400 00[1]
PUBLIC UTILITIES	60000 00
MUNICIPAL UTILITIES - TREE DIVISION	64000 00[2]
REGIONAL, COUNTY, AND CITY AGENCIES	70000 00[3]
DIV OF FORESTRY (CITY OR COUNTY)	70100 00
PARKS AND RECREATION (CITY OR COUNTY)	70100 00
PARKS AND RECREATION (REGIONAL)	70100 001
PUBLIC WORKS - TREE DIV (CITY OR COUNTY)	70700 00
STATE AGENCIES	
CALIFORNIA	
AGRICULTURE, DEPT OF FOOD AND	51900 00
CONSERVATION, DEPT OF (FORESTRY)	51200 00
	-51600 00
FISH AND GAME, DEPT OF	51800 00
OTHER AGENCIES (STATE)	58000 00
PARKS AND RECREATION, DEPT OF	52000 00
TRANSPORTATION, DEPT OF (HIGHWAYS)	51700 00
COLORADO DEPT OF FISH AND GAME	51800 00
NEVADA STATE PARKS	52000 00
NEW MEXICO STATE PARKS AND RECREATION	52403 00
OREGON	
FORESTRY, DEPT OF	51200 00
PARKS AND RECREATION, DEPT OF	52000 00
UTAH DEPT OF PARKS AND RECREATION	52000 00
WASHINGTON	
NATURAL RESOURCES, DEPT OF	51200 00
PARKS AND RECREATION, DEPT OF	52000 00
OTHER STATE AGENCIES	58000 00

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[1] EX: CITY OF BERKELEY, PRIVATE GROUNDS 70403 40

[2] EX: CASITAS MUNICIPAL WATER DIST., OJAI, CA. 64025 30

[3] EX: CITY OF L.A. PARKS + REC 70119 80
CITY OF L.A. STREET TREE DIV 70719 80
COUNTY OF L.A. PARKS + REC 70100 00
EAST BAY REGIONAL PARK DISTRICT 70100 001
SHASTA COUNTY DEPT OF PUBLIC WORKS 70700 00

NOTE THAT ALTHOUGH CITY AGENCIES GENERALLY ARE CODED IN THE 70000 00 SERIES, MUNICIPAL UTILITIES ARE CODED 64000 00 IN THE CODE SERIES FOR PUBLIC UTILITIES.

AGENCY CODES—DETAIL

Forest Service 01000 00

REGION 1 - NORTHERN REGION 01100 00

MONTANA/N.IDAHO/N.DAKOTA/E.WASHINGTON

CLEARWATER FOREST		01101 00
	CANYON	01101 02
	KELLY CREEK	01101 03
	LOCHSA	01101 04
	PALOUSE	01101 07
	PIERCE	01101 05
	POWELL	01101 06
NEZPERCE		01104 00
	CLEARWATER	01104 01
	ELK CITY	01104 03
	MOOSE CREEK	01104 04
	RED RIVER	01104 05
	SALMON RIVER	01104 06
	SELWAY	01104 07
BEAVERHEAD		01106 00
	DILLON	01106 01
	MADISON	01106 03
	SHERIDAN	01106 04
	WISDOM	01106 05
	WISE RIVER	01106 06
BITTERROOT		01107 00
	DARBY	01107 01
	STEVENSVILLE	01107 03
	SULA	01107 04
	WEST FORK	01107 05
CUSTER		01108 00
	ASHLAND	01108 01
	BEAR TOOTH	01108 02
	FORT HOWES	01108 03
	GRAND RIVER	01108 04
	MCKENZIE	01108 05
	MEDORA	01108 06
	SHEYENNE	01108 07
	SIOUX	01108 08
DEERLODGE		01109 00
	BUTTE	01109 02
	DEERLODGE	01109 03
	JEFFERSON	01109 01
	PHILIPSBURG	01109 04
FLATHEAD		01110 00
	GLACIER VIEW	01110 04
	HUNGRY HORSE	01110 05
	SPOTTED BEAR	01110 06
	SWAN LAKE	01110 07
	TALLY LAKE	01110 08
GALLATIN		01111 00
	BIG TIMBER	01111 01
	BOZEMAN	01111 02
	GALLATIN	01111 03
	GARDINER	01111 04
	HEBGEN LAKE	01111 05
	LIVINGSTON	01111 06
HELENA		01112 00
	CANYON FERRY	01112 01
	HELENA	01112 02
	LINCOLN	01112 03
	TOWNSEND	01112 04
KOOTENAI		01113 00
	CABINET	01113 08
	FISHER RIVER	01113 01
	FORTINE	01113 02
	LIBBY	01113 03
	REXFORD	01113 04
	TROY	01113 05
	YAAK	01113 07
LEWIS + CLARK		01114 00
	BELT CREEK	01114 01
	JUDITH	01114 02
	MUSSELSHELL	01114 03
	SUN RIVER	01114 04
	TETON	01114 05
	WHITE SULPHUR	01114 06
LOLO		01115 00
	MISSOULA	01115 02
	NINE MILE	01115 03
	PLAINS	01115 04
	SEELEY LAKE	01115 05
	SUPERIOR	01115 07
	THOMPSON FALLS	01115 08
IDAHO PANHANDLE NF'S		01117 00
	AVERY	01117 01
	BONNERS FERRY	01117 02
	FERNAN	01117 03
	PRIEST LAKE	01117 04
	RED IVES	01117 05
	ST. MARIES	01117 06
	SANDPOINT	01117 07
	WALLACE	01117 08

REGION 2 - ROCKY MT. REGION		01200 00
WYO/COLO/S.DAK/NEBR/KANS		
ARAPAHO-ROOSEVELT		01216 00
	BOULDER	01216 01
	CLEAR CREEK	01216 02
	ESTES PARK	01216 03
	PAWNEE N.G.	01216 04
	POUDRE	01216 05
	REDFEATHER	01216 06
	SULPHUR	01216 07
GRAND MESA-UNCOMPAHGRE		01202 00
	COLLBRAN	01202 01
	GRAND JUNCT	01202 10
	MIGUEL	01202 03
	NORWOOD	01202 05
	OURAY	01202 06
	CEBOLLA	01202 07
	PAONIA	01202 08
	TAYLOR RIVER	01202 09
PIKE-SAN ISABEL		01217 00
	CARRIZO	01217 01
	CIMARRON NG	01217 02
	LEADVILLE	01217 04
	PIKES PEAK	01217 05
	SALIDA	01217 06
	SAN CARLOS	01217 07
	SOUTH PARK	01217 08
	SOUTH PLATTE	01217 09
RIO GRANDE		01205 00
	ALAMOSA	01205 01
	CONEJOS	01205 03
	CREEDE	01205 04
	DEL NORTE	01205 05
	SAGUACHE	01205 06
ROUTT		01207 00
	BEARS EARS	01207 01
	HAHNS PEAK	01207 03
	MIDDLE PARK	01207 06
	NORTH PARK	01207 04
	YAMPA	01207 05
SAN JUAN		01209 00
	ANIMAS	01209 01
	DOLORES	01209 02
	MANCOS	01209 04
	PAGOSA	01209 05
	PIEDRA	01209 06
	PINE	01209 07

WHITE RIVER		01210 00
	ASPEN	01210 01
	BLANCO	01210 02
	DILLON	01210 09
	EAGLE	01210 04
	HOLY CROSS	01210 07
	RIFLE	01210 08
	SOPRIS	01210 10
NEBRASKA		01211 00
	BESSEY	01211 01
	BUFFALO GAP NG	01211 08
	FALL RIVER	01211 03
	FT PIERRE NG	01211 06
	OGLALA NG	01211 05
	PINE RIDGE	01211 02
	PINE RIDGE CCC	01211 07
	WALL	01211 04
BLACK HILLS		01212 00
	BEARLODGE	01212 01
	CUSTER	01212 02
	ELK MTN	01212 03
	HARNEY	01212 04
	NEMO	01212 05
	PACTOLA	01212 06
	SPEARFISH	01212 08
BIGHORN		01213 00
	BUFFALO	01213 01
	MEDICINE WHEEL	01213 02
	PAINTROCK	01213 03
	TENSLEEP	01213 04
	TONGUE	01213 05
MEDICINE BOW		01214 00
	BRUSH CREEK	01214 02
	ENCAMPMENT	01214 04
	LARAMIE	01214 09
	LARAMIE PEAK	01214 06
	SNAKE RIVER	01214 08
	THUNDER BASIN NG	01214 10
SHOSHONE		01215 00
	CLARKS FORK	01215 01
	GREYBULL	01215 02
	LANDER	01215 03
	WAPITI	01215 04
	WIND RIVER	01215 05

REGION 3 - SOUTHWESTERN REGION		01300 00
NEW MEXICO/ARIZONA		
APACHE-SITGREAVES		01313 00
	ALPINE	01313 01
	BLACK RIVER	01313 02
	CHEVELON	01313 03
	CLIFTON	01313 04
	HEBER	01313 05
	LAKESIDE	01313 06
	PINEDALE	01313 07
	SPRINGERVILLE	01313 08
COCONINO		01302 00
	BEAVER CREEK	01302 01
	BLUE RIDGE	01302 02
	ELDEN	01302 03
	FLAGSTAFF	01302 07
	LONG VALLEY	01302 04
	MORMON LAKE	01302 05
	SEDONA	01302 06
CORONADO		01303 00
	DOUGLAS	01303 01
	NOGALES	01303 02
	SAFFORD	01303 04
	SANTA CATALINA	01303 05
	SIERRA VISTA	01303 08
KAIBAB		01304 00
	CHALENDER	01304 02
	NORTH KAIBAB	01304 06
	TUSAYAN	01304 04
	WILLIAMS	01304 05
PRESCOTT		01305 00
	CHINO VALLEY	01305 01
	CROWN KING	01305 02
	THUMB BUTTE	01305 07
	VERDE	01305 05
	WALNUT CREEK	01305 06
TONTO		01307 00
	CAVE CREEK	01307 01
	GLOBE	01307 02
	MESA	01307 03
	PAYSON	01307 04
	PLEASANT VALLEY	01307 05
	TONTO BASIN	01307 07
CARSON		01308 00
	CANJILON	01308 01
	EL RITO	01308 02
	JICARILLA	01308 03
	PENASCO	01308 04
	QUESTA	01308 05
	TAOS	01308 06
	TRES PIEDRAS	01308 07
CIBOLA		01309 00
	BLACK KETTLE	01309 06
	KIOWA	01309 07
	MAGDALENA	01309 03
	MT. TAYLOR	01309 08
	MOUNTAINAIR	01309 04
	RITA BLANCA	01309 09
	SANDIA	01309 05
GILA		01310 00
	BEAVERHEAD	01310 01
	BLACK RANGE	01310 02
	GLENWOOD	01310 04
	LUNA	01310 09
	MIMBRES	01310 05
	QUEMADO	01310 10
	RESERVE	01310 06
	SILVER CITY	01310 07
	WILDERNESS	01310 08
LINCOLN		01311 00
	CLOUDCROFT	01311 01
	GUADALUPE	01311 02
	MAYHILL	01311 03
	SMOKY BEAR	01311 06
SANTA FE		01312 00
	COYOTE	01312 01
	CUBA	01312 02
	ESPANOLA	01312 03
	JEMEZ	01312 07
	LAS VEGAS	01312 04
	PECOS	01312 05
	TESUQUE	01312 06

REGION 4 - INTERMOUNTAIN REGION 01400 00

SO. IDAHO/NEV/UTAH/WEST. WYOMING

BOISE		
	BOISE	01401 00
	CASCADE	01401 03
	EMMETT	01401 05
	IDAHO CITY	01401 07
	LOWMAN	01401 09
	MOUNTAIN HOME	01401 10
CARIBOU		01402 00
	MALAD	01402 03
	MONTPELIER	01402 04
	POCATELLO	01402 05
	SODA SPRINGS	01402 06
CHALLIS		01403 00
	CHALLIS	01403 01
	LOST RIVER	01403 06
	MIDDLE FORK	01403 07
	YANKEE FORK	01403 08
PAYETTE		01404 00
	BIG CREEK	01404 01
	COUNCIL	01404 03
	KRASSEL	01404 05
	MCCALL	01404 06
	NEW MEADOWS	01404 07
	WEISER	01404 09
SALMON		01405 00
	COBALT	01405 01
	LEADORE	01405 03
	NORTH FORK	01405 04
	SALMON	01405 05
SAWTOOTH		01406 00
	BURLEY	01406 01
	FAIRFIELD	01406 02
	KETCHUM	01406 04
	SAWTOOTH NRA	01406 09
	TWIN FALLS	01406 08
TARGHEE		01407 00
	ASHTON	01407 01
	DUBOIS	01407 03
	ISLAND PARK	01407 02
	PALISADES	01407 04
	TETON BASIN	01407 08
HUMBOLDT		01408 00
	ELY	01408 01
	JARBIDGE	01408 03
	MOUNTAIN CITY	01408 05
	RUBY MTNS	01408 09
	SANTA ROSA	01408 06
	WHITE PINE	01408 08
TOIYABE		01409 00
	AUSTIN	01409 02
	BRIDGEPORT	01409 03
	CARSON	01409 04
	LAS VEGAS	01409 06
	TONOPAH	01409 07

ASHLEY		01410 00
	DUCHESNE	01410 02
	FLAMING GORGE	01410 03
	ROOSEVELT	01410 04
	VERNAL	01410 05
DIXIE		01412 00
	CEDAR CITY	01412 01
	ESCALANTE	01412 04
	PINE VALLEY	01412 06
	POWELL	01412 07
	TEASDALE	01412 08
FISHLAKE		01413 00
	BEAVER	01413 01
	FILLMORE	01413 02
	LOA	01413 05
	RICHFIELD	01413 08
MANTI-LASAL		01414 00
	FERRON	01414 03
	MOAB	01414 05
	MONTICELLO	01414 06
	PRICE	01414 08
	SANPETE	01414 09
UINTA		01415 00
	HEBER	01415 01
	PLEASANT GROVE	01415 03
	SPANISH FORK	01415 04
WASATCH		01416 00
	EVANSTON	01416 02
	KAMAS	01416 03
	LOGAN	01416 07
	MOUNTAIN VIEW	01416 04
	OGDEN	01416 08
	SALT LAKE	01416 05
	TOOELE	01416 05
BRIDGER-TETON		01419 00
	BIG PINEY	01419 01
	BUFFALO	01419 02
	GREYS RIVER	01419 03
	GROS VENTRE	01419 04
	HOBACK	01419 05
	KEMMERER	01419 06
	PINEDALE	01419 07

REGION 5 - CALIFORNIA REGION		01500 00
CALIFORNIA/HAWAII		
ANGELES		01501 00
	ARROYO-SECO	01501 01
	MT BALDY	01501 02
	SAUGUS	01501 03
	TUJUNGA	01501 04
	VALYERMO	01501 05
CLEVELAND		01502 00
	DESCANSO	01502 01
	PALOMAR	01502 02
	TRABUCO	01502 03
ELDORADO		01503 00
	AMADOR	01503 01
	GEORGETOWN	01503 03
	PACIFIC	01503 05
	PLACERVILLE	01503 06
INYO		01504 00
	MAMMOTH	01504 01
	MONO LAKE	01504 02
	MT WHITNEY	01504 03
	WHITE MTN	01504 04
KLAMATH		01505 00
	GOOSENEST	01505 02
	HAPPY CAMP	01505 03
	OAK KNOLL	01505 04
	SALMON RIVER	01505 05
	SCOTT RIVER	01505 06
	UKONOM	01505 08
LASSEN		01506 00
	ALMANOR	01506 01
	EAGLE LAKE	01506 07
	HAT CREEK	01506 03
LOS PADRES		01507 00
	MONTEREY	01507 02
	MT PINOS	01507 03
	OJAI	01507 04
	SANTA BARBARA	01507 06
	SANTA LUCIA	01507 07
MENDOCINO		01508 00
	CORNING	01508 01
	COVELO	01508 02
	STONYFORD	01508 03
	UPPER LAKE	01508 05
MODOC		01509 00
	BIG VALLEY	01509 01
	DEVIL'S GARDEN	01509 02
	DOUBLEHEAD	01509 03
	WARNER MOUNTAIN	01509 07
PLUMAS		01510 00
	BECKWOURTH	01510 01
	GREENVILLE	01510 02
	LAPORTE	01510 03
	MILFORD	01510 05
	QUINCY	01510 06
	OROVILLE	01510 07

SAN BERNARDINO		01511 00
	ARROWHEAD	01511 01
	BIG BEAR	01511 02
	CAJON	01511 03
	SAN GORGONIO	01511 04
	SAN JACINTO	01511 05
SEQUOIA		01512 00
	CANNELL MEADOW	01512 05
	GREENHORN	01512 04
	HOT SPRINGS	01512 03
	HUME LAKE	01512 01
	TULE RIVER	01512 02
SHASTA-TRINITY		01513 00
	BIG BAR	01513 01
	HAYFORK	01513 03
	MCCLOUD	01513 04
	MT SHASTA	01513 05
	SHASTA LAKE	01513 06
	WEAVERVILLE	01513 07
	YOLLA BOLLA	01513 08
SIERRA		01514 00
	BASS LAKE	01514 01
	KINGS RIVER	01514 03
	MARIPOSA	01514 04
	MINARETS	01514 05
	PINERIDGE	01514 07
SIX RIVERS		01515 00
	GASQUET	01515 01
	LOWER TRINITY	01515 05
	MAD RIVER	01515 02
	ORLEANS	01515 03
STANISLAUS		01516 00
	CALAVERAS	01516 01
	GROVELAND	01516 02
	MI-WOK	01516 03
	SUMMIT	01516 04
TAHOE		01517 00
	DOWNIEVILLE	01517 03
	FORESTHILL	01517 04
	NEVADA CITY	01517 05
	SIERRAVILLE	01517 06
	TRUCKEE	01517 07
LAKE TAHOE BASIN MGMT UNIT		01518 00

REGION 6 - PACIFIC NORTHWEST REGION 01600 00

OREGON/WASHINGTON

DESCHUTES		01601 00
	BEND	01601 01
	CRESCENT	01601 02
	FORT ROCK	01601 03
	SISTERS	01601 04
FREMONT		01602 00
	BLY	01602 01
	LAKEVIEW	01602 02
	PAISLEY	01602 03
	SILVER LAKE	01602 04
MALHEUR		01603 00
	BEAR VALLEY	01603 01
	BURNS	01603 02
	LONG CREEK	01603 03
	PRAIRIE CITY	01603 04
MT HOOD		01604 00
	BARLOW	01604 01
	BEAR SPRINGS	01604 02
	CLACKAMAS	01604 09
	COLUMBIA GORGE	01604 04
	ESTACADA	01604 05
	HOOD RIVER	01604 06
	ZIGZAG	01604 08
OCHOCO		01605 00
	BIG SUMMIT	01605 01
	BURNS FIRE ZONE	01605 06
	CROOKED RIVER NG	01605 05
	PAULINA	01605 02
	PRINEVILLE	01605 03
	SNOW MOUNTAIN	01605 04
ROGUE RIVER		01606 00
	APPLEGATE	01606 01
	ASHLAND	01606 02
	BUTTE FALLS	01606 03
	PROSPECT	01606 04
SISKIYOU		01607 00
	CHETCO	01607 01
	GALICE	01607 02
	GOLD BEACH	01607 03
	ILLINOIS VALLEY	01607 04
	POWERS	01607 05
SIUSLAW		01608 00
	ALSEA	01608 01
	HEBO	01608 02
	MAPLETON	01608 03
	WALDPORT	01608 05
	OREGON DUNES NRA	01608 36
UMATILLA		01609 00
	DALE	01609 01
	HEPPNER	01609 02
	PENDLETON	01609 03
	POMEROY	01609 04
	UKIAH	01609 05
	WALLA WALLA	01609 06
UMPQUA		01610 00
	COTTAGE GROVE	01610 01
	DIAMOND LAKE	01610 02
	GLIDE	01610 03
	STEAMBOAT	01610 05
	TILLER	01610 06

WALLOWA-WHITMAN		01611 00
	BAKER	01611 01
	BEAR-SLEDS	01611 02
	CHESNIMNUS	01611 03
	JOSEPH	01611 04
	LAGRANDE	01611 05
	PINE	01611 06
	UNION	01611 07
	UNITY	01611 08
WILLAMETTE		01612 00
	BLUE RIVER	01612 01
	DETROIT	01612 02
	LOWELL	01612 03
	MCKENZIE	01612 04
	OAKRIDGE	01612 06
	RIGDON	01612 07
	SWEET HOME	01612 08
WINEMA		01613 00
	CHEMULT	01613 01
	CHILOQUIN	01613 02
	KLAMATH	01613 03
GIFFORD PINCHOT		01614 00
	ST HELENS	01614 01
	MT ADAMS	01614 03
	PACKWOOD	01614 04
	RANDLE	01614 05
	WIND RIVER	01614 06
OKANOGAN		01616 00
	CONCONCULLY	01616 01
	TONASKET	01616 02
	TWISP	01616 03
	WINTHROP	01616 04
OLYMPIC		01617 00
	HOODSPORT	01617 01
	QUILCENE	01617 02
	QUINAULT	01617 03
	SHELTON	01617 04
	SOLEDUCK	01617 05
WENATCHEE		01619 00
	CHELAN	01619 01
	CLE ELUM	01619 02
	ELLENSBURG	01619 03
	ENTIAT	01619 04
	LAKE WENATCHEE	01619 05
	LEAVENWORTH	01619 06
	NACHES	01619 07
	TIETON	01619 08

COLVILLE		01620 00
	COLVILLE	01620 01
	KETTLE FALLS	01620 02
	NEWPORT	01620 05
	REPUBLIC	01620 03
	SULLIVAN LAKE	01620 04
MT BAKER-SNOQUALMIE		01621 00
	BAKER RIVER	01621 01
	DARRINGTON	01621 02
	GLACIER	01621 03
	MONTE CRISTO	01621 04
	NORTH BEND	01621 05
	SKYKOMISH	01621 06
	WHITE RIVER	01621 07

REGION 8 - SOUTHERN REGION 01800 00

ALABAMA

WILLIAM B BANKHEAD		01801 00
	BANKHEAD	01801 01
	BLACK WARRIOR	01801 02
CONECUH		01802 00
	CONECUH	01802 01
TALLADEGA		01803 00
	OAKMULGEE	01803 01
	SHOAL CREEK	01803 02
	TALLADEGA	01803 03
TUSKEGEE		01804 00
	TUSKEGEE	01804 01

ARKANSAS

OUACHITA		01805 00
	CADDO	01805 01
	CHOCTAW	01805 02
	COLD SPRINGS	01805 03
	FOURCHE	01805 04
	JESSIEVILLE	01805 05
	KLAMICHI	01805 06
	MENA	01805 07
	ODEN	01805 08
	POTEAU	01805 09
	TIAK	01805 10
	WINONA	01805 11
	WOMBLE	01805 12
OZARK AND ST FRANCIS		01806 00
OZARK		01807 00
	BAYOU	01807 01
	BOSTON MT	01807 02
	BUFFALO	01807 03
	MT MAGAZINE	01807 04
	PLEASANT HILL	01807 05
	SYLAMORE	01807 07
ST FRANCIS		01808 00
	ST FRANCIS	01808 01

FLORIDA

APALACHICOLA		01809 00
	APALACHICOLA	01809 01
	WAKULLA	01809 02
OCALA		01810 00
	LAKE GEORGE	01810 01
	SEMINOLE	01810 02
OSCEOLA		01811 00
	OSCEOLA	01811 01

GEORGIA

CHATTAHOOCHEE		01812 00
	ARMUCHEE	01812 01
	BRASSTOWN	01812 02
	CHATTOOGA	01812 03
	CHESTATEE	01812 04
	COHUTTA	01812 05
	TALLULAH	01812 06
	TOCCOA	01812 07
OCONEE		01813 00
	OCONEE	01813 01

KENTUCKY

DANIEL BOONE		01814 00
	BEREA	01814 01
	LONDON	01814 02
	MOREHEAD	01814 03
	REDBIRD	01814 04
	SOMERSET	01814 05
	STANTON	01814 06
	STEARNS	01814 07

LOUISIANA

KISATCHIE		01815 00
	CANEY	01815 01
	CATAHOULA	01815 02
	EVANGELINE	01815 03
	KISATCHIE	01815 04
	VERNON	01815 05
	WINN	01815 06
	S+PF SITES	01815 10

MISSISSIPPI

BIENVILLE		01816 00
	BIENVILLE	01816 01
	STRONG RIVER	01816 02
DELTA		01817 00
	DELTA	01817 01
DESOTO		01818 00
	BILOXI	01818 01
	BLACK CREEK	01818 02
	CHICKASAWNAY	01818 03
HOLLY SPRINGS		01819 00
	HOLLY SPRINGS	01819 01
HOMOCHITTO		01820 00
	BUDE	01820 01
	HOMOCHITTO	01820 02
TOMBIGBEE		01821 00
	TOMBIGBEE	01821 01

NORTH CAROLINA

CROATAN		01822 00
	CROATAN	01822 01
NANTAHALA		01823 00
	CHEOAH	01823 01
	HIGHLAND	01823 02
	TUSQUITTEE	01823 03
	WAYAH	01823 04
PISGAH		01824 00
	FRENCH BROAD	01824 01
	GRANDFATHER	01824 02
	PISGAH	01824 03
	TOECANE	01824 04
UWHARRIE		01825 00
	UWHARRIE	01825 01

PUERTO RICO

CARIBBEAN		01837 00

SOUTH CAROLINA

FRANCIS MARIAN AND SUMTER NF		01826 00
FRANCIS MARIAN		01827 00
	WAMBAW	01827 02
	WITHERBEE	01827 03
SUMTER		01828 00
	ANDREW PICKENS	01828 01
	EDGEFIELD	01828 02
	ENOREE	01828 03
	LONG CANE	01828 04
	TYGER	01828 05

TENNESSEE

CHEROKEE		01829 00
	HIWASSEE	01829 01
	NOLICHUCKY	01829 02
	OCOEE	01829 03
	TELLICO	01829 04
	UNAKA	01829 05
	WATAUGA	01829 06

TEXAS

ANGELINA		01831 01
	ANGELINA	01831 01
DAVY CROCKETT		01832 00
	NECHES	01832 01
	TRINITY	01832 02
SABINE		01833 00
	TENAHA	01833 01
	YELLOWPINE	01833 02
SAM HOUSTON		01834 00
	RAVEN	01834 02
	SAN JACINTO	01834 03

VIRGINIA

GEORGE WASHINGTON		01835 00
	DEERFIELD	01835 02
	DRY RIVER	01835 03
	JAMES RIVER	01835 04
	LEE	01835 05
	PEDLAR	01835 06
	WARM SPRINGS	01835 07
JEFFERSON		01836 00
	BLACKSBURG	01836 01
	CLINCH	01836 02
	GLENWOOD	01836 03
	MT ROGERS NRA	01836 07
	NEW CASTLE	01836 05
	WYTHE	01836 06

REGION 9 - EASTERN REGION 01900 00

N.EAST/GREAT LAKES

SHAWNEE		01901 00
	ELIZABETHTOWN	01901 01
	JONESBORO	01901 02
	MURPHYSBORO	01901 03
	VIENNA	01901 04
WAYNE-HOOSIER		01902 00
	ATHENS	01902 03
	BROWNSTOWN	01902 01
	IRONTON	01902 04
	TELL CITY	01902 02
HIAWATHA		01903 00
	EASTERN C+M UNIT	01903 02
	MANISTIQUE	01903 03
	MUNISING	01903 04
	RAPID RIVER	01903 05
	ST IGNACE	01903 06
	SAULT STE. MARIE	01903 07
	WESTERN C+M UNIT	01903 01
HURON-MANISTEE		01904 00
	BALDWIN	01904 01
	CADILLAC	01904 02
	HARRISVILLE	01904 03
	MANISTEE	01904 04
	MIO	01904 05
	TAWAS	01904 06
	WHITE CLOUD	01904 07
OTTAWA		01905 00
	BERGLAND	01905 01
	BESSEMER	01905 02
	EASTERN ENG UNIT	01905 07
	IRON RIVER	01905 03
	KENTON	01905 04
	ONTONAGON	01905 05
	WATERSMEET	01905 06
	WESTERN ENG UNIT	01905 08
CHIPPEWA		01906 00
	BLACKDUCK	01906 02
	CASS LAKE	01906 03
	DEER RIVER	01906 10
	MARCELL	01906 05
	NORTH C+M UNIT	01906 08
	SOUTH C+M UNIT	01906 09
	WALKER	01906 07
SUPERIOR		01907 00
	AURORA	01907 07
	EASTERN C+M UNIT	01907 01
	GUNFLINT	01907 08
	ISABELLA	01907 10
	KAWISHIWI	01907 11
	LA CROIX	01907 12
	NORTHERN C+M UNIT	01907 02
	SOILS UNIT	01907 05
	SOUTHERN C+M UNIT	01907 03
	TOFTE	01907 13
	TWO HARBORS	01907 14
	VIRGINIA	01907 15
	WATERSHED UNIT	01907 06

MARK TWAIN		01909 00
	AVA	01909 01
	CASSVILLE	01909 02
	CEDAR CRK LU PROJ	01909 13
	DONIPHAN	01909 03
	FREDERICKTOWN	01909 07
	HOUSTON	01909 08
	POPLAR BLUFF	01909 09
	POTOSI	01909 10
	ROLLA	01909 11
	SALEM	01909 12
	VAN BUREN	01909 04
	WILLOW SPRINGS	01909 05
	WINONA	01909 06
WHITE MOUNTAIN		01910 00
	AMMONOOSUC	01910 01
	ANDROSCOGGIN	01910 02
	EVANS NOTCH	01910 03
	PEMIGEWASSET	01910 04
	SACO	01910 05
ALLEGHENY		01911 00
	BRADFORD	01911 01
	MARIENVILLE	01911 02
	RIDGEWAY	01911 03
	SHEFFIELD	01911 04
GREEN MOUNTAIN		01912 00
	HECTOR LU AREA	01912 04
	MANCHESTER	01912 01
	MIDDLEBURY	01912 02
	ROCHESTER	01912 03
MONONGAHELA		01913 00
	CHEAT	01913 01
	GAULEY	01913 02
	GREENBRIAR	01913 03
	MARLINTON	01913 04
	POTOMAC	01913 05
	WHITE SULPHUR	01913 06
CHEQUAMEGON		01914 00
	GLIDDEN	01914 01
	HAYWARD	01914 02
	MEDFORD	01914 03
	PARK FALLS	01914 04
	WASHBURN	01914 05
NICOLET		01915 00
	EAGLE RIVER	01915 02
	FLORENCE	01915 03
	LAKEWOOD	01915 04
	LAONA	01915 05
	THREE LAKES	01915 01

REGION 10- ALASKA REGION		01700 00
ALASKA		
CHUGACH		01701 00
	WORK CENTER (ANCHORAGE)	01701 04
TONGAS		01704 00
	CHATHAM AREA	01704 01
	KETCHIKAN AREA	01704 02
	STIKINE AREA	01704 03

National Park Service 02000 00

BY REGION

WESTERN REGION	02100 00
CHANNEL ISLANDS NM	02138 00
CHIRICAHUA NM	02113 00
DEATH VALLEY NM	02139 00
GRAND CANYON NP	02101 00
HALEAKALA NP	02135 00
HAWAII VOLCANOES NP	02136 00
LAKE MEAD NRA	02141 00
LASSEN VOLCANIC NP	02124 00
MONTEZUMA CASTLE NM	02117 00
MUIR WOODS NM	02131 00
PINNACLES NM	02132 00
POINT REYES NS	02133 00
SAGUARO NM	02119 00
SEQUOIA-KINGS NP	02122 00
LODGEPOLE RAN. STA.	02122 01
TONTO NM	02145 00
TUMACACORI NM	02143 00
WALNUT CANYON NM	02144 00
YOSEMITE NP	02121 00
WHISKEYTOWN-SHASTA-TRINITY NRA	02134 00
REDWOOD NATL PARK	02142 00
NORTH DISTRICT	02142 01

PACIFIC NORTHWEST REGION	02600 22
COULEE DAM NRA	02601 22
CRATER LAKE NP	02602 22
CRATERS OF THE MOON NM	02603 22
GLACIER BAY NM	02640 22
KATMAI NM	02607 22
LAKE CHELAN NRA	02608 22
LAVA BEDS NM	02637 22
MOUNT MCKINLEY NP	02604 22
MOUNT RAINIER NP	02605 22
NORTH CASCADES NP	02612 22
OLYMPIC NP	02606 22
OREGON CAVES NM	02609 22
ROSS LAKE NRA	02610 22
SAN JUAN ISLAND NHP	02647 22
SITKA NHP	02611 22
WHITMAN MISSION NHS	02646 22

MIDWEST REGION	02200 00
OZARK NAT. SCENIC RIVERWAYS	02211 00

SOUTHWEST REGION	02300 00
BANDELIER NM	02310 00
BIG BEND NP	02302 00
CAPULIN MOUNTAIN NM	02312 00
CARLSBAD CAVERNS NP	02304 00
CHICKASAW NRA	02321 00
FORT DAVIS NHS	02314 00
GILA CLIFF DWELLINGS NM	02315 00
GUADALUPE MTNS NP	02306 00
PLATT NP-ARBUCKLE	02308 00
SUNSET CRATER NM	02320 00

ROCKY MOUNTAIN REGION	02400 00
ARCHES NP	02419 00
BIGHORN CANYON NRA	02414 00
BRYCE CANYON NP	02406 00
CAPITOL REEF NP	02410 00
CEDAR BREAKS NM	02407 00
DEVIL'S TOWER NM	02404 00
DINOSAUR NM	02405 00
GLACIER NP	02413 00
GRAND TETON NP	02401 00
GREAT SAND DUNES NM	02411 00
MESA VERDE NP	02408 00
PIPE SPRING NM	02418 00
ROCKY MOUNTAIN NP	02403 00
TIMPANAGOS CAVE NM	02412 00
WATERTON-GLACIER	02415 00
INTERNATIONAL PEACE PRK	02415 00
WATERTON LAKES NP	02416 00
WIND CAVE NP	02417 00
YELLOWSTONE NP	02402 00
NOTE- COUNTY = 024 FOR YELLOWSTONE N P	
ZION NP	02409 00

MID ATLANTIC REGION	02500 00

SOUTHEAST REGION	02700 00

NORTH ATLANTIC REGION	02800 00

NATIONAL CAPITAL	02900 00

NUMERIC 02000 00

REGIONAL SOLICITOR	02000 002
GRAND CANYON NP	02101 00
CHIRICAHUA NM	02113 00
MONTEZUMA CASTLE NM	02117 00
SAGUARO NM	02119 00
YOSEMITE NP	02121 00
SEQUOIA-KINGS NP	02122 00
LODGEPOLE RAN. STA.	02122 01
LASSEN VOLCANIC NP	02124 00
MUIR WOODS NM	02131 00
PINNACLES NM	02132 00
POINT REYES NS	02133 00
WHISKEYTOWN-SHASTA-TRINITY NRA	02134 00
HALEAKALA NP	02135 00
HAWAII VOLCANOES NP	02136 00
CHANNEL ISLANDS NM	02138 00
DEATH VALLEY NM	02139 00
LAKE MEAD NRA	02141 00
REDWOOD NATL PARK	02142 00
NORTH DISTRICT	02142 01
TUMACACORI NM	02143 00
WALNUT CANYON NM	02144 00
TONTO NM	02145 00
OZARK NAT. SCENIC RIVERWAYS	02211 00
BIG BEND NP	02302 00
CARLSBAD CAVERNS NP	02304 00
GUADALUPE MTNS NP	02306 00
PLATT NP-ARBUCKLE	02308 00
BANDELIER NM	02310 00
CAPULIN MOUNTAIN NM	02312 00
FORT DAVIS NHS	02314 00
GILA CLIFF DWELLINGS NM	02315 00
SUNSET CRATER NM	02320 00
CHICKASAW NRA	02321 00
GRAND TETON NP	02401 00
YELLOWSTONE NP	02402 00
ROCKY MOUNTAIN NP	02403 00
DEVIL'S TOWER NM	02404 00
DINOSAUR NM	02405 00
BRYCE CANYON NP	02406 00
CEDAR BREAKS NM	02407 00
MESA VERDE NP	02408 00
ZION NP	02409 00
CAPITOL REEF NP	02410 00
GREAT SAND DUNES NM	02411 00
TIMPANAGOS CAVE NM	02412 00
GLACIER NP	02413 00
BIGHORN CANYON NRA	02414 00
WATERTON-GLACIER	02415 00
INTERNATIONAL PEACE PRK	02415 00
WATERTON LAKES NP	02416 00
WIND CAVE NP	02417 00
PIPE SPRING NM	02418 00
ARCHES NP	02419 00
COULEE DAM NRA	02601 22
CRATER LAKE NP	02602 22
CRATERS OF THE MOON NM	02603 22
MOUNT MCKINLEY NP	02604 22
MOUNT RAINIER NP	02605 22
OLYMPIC NP	02606 22
KATMAI NM	02607 22
LAKE CHELAN NRA	02608 22
OREGON CAVES NM	02609 22
ROSS LAKE NRA	02610 22
SITKA NHP	02611 22
NORTH CASCADES NP	02612 22
LAVA BEDS NM	02637 22
GLACIER BAY NM	02640 22
WHITMAN MISSION NHS	02646 22
SAN JUAN ISLAND NHP	02647 22

Bureau of Indian Affairs/Indian Tribal Lands 03000 00

SACRAMENTO AREA	03101 00
PORTLAND AREA	03202 00
PHOENIX AREA	03307 00
UINTAH AND OURAY	03900 00
NAVAJO AREA	03407 00
ALBUQUERQUE AREA	03511 00
ZUNI	03511 01
NORTHERN PUEBLOS	03511 02
SOUTHERN UTE	03905 00
ABERDEEN AREA	03613 00
STANDING ROCK	03613 01
WINNEBAGO	03613 02
FT TOTTEN	03613 03
ROSEBUD	03613 04
BILLINGS AREA	03708 00
JUNEAU AREA	03821 00

NOTE: FOR CONVENIENCE, OFFICES OF THE BUREAU OF INDIAN AFFAIRS ARE CODED IN THE SAME SERIES AS THAT DESIGNATED FOR SITES ON AMERICAN INDIAN TRIBAL LANDS.

Fish and Wildlife Service 04000 00

REGION 1	04100 00

CALIFORNIA	04101 00
CLEAR LAKE NWR	04101 01
COLUSA NWR	04101 02
HAVASU NWR	04101 03
IMPERIAL NWR	04101 04
KERN NWR	04101 05
LOWER KLAMATH NWR	04101 06
MERCED NWR	04101 07
MODOC NWR	04101 08
PIXLEY NWR	04101 09
SACRAMENTO NWR	04101 10
SALTON SEA NWR	04101 11
SUTTER NWR	04101 12
TULELAKE NWR	04101 13

IDAHO	04104 00
CAMAS NWR	04104 01
DEER FLAT NWR	04104 02
MINIDOKA NWR	04104 03
SNAKE RIVER NWR	04104 04

MONTANA	04108 00
BENTON LAKE WR	04108 01
BLACK COULEE WR	04108 02
BOWDOIN WR	04108 03
CREEDMAN COULEE WR	04108 04
FORT PECK GAME RANGE	04108 05
HAILSTONE WR	04108 06
HALFBREED LAKE WR	04108 07
HEWITT LAKE WR	04108 08
LAMESTEER WR	04108 09
MASON LAKE WR	04108 10
MEDICINE LAKE WR	04108 11
NATIONAL BISON RANGE	04108 12
NINE PIPE WR	04108 13
PABLO WR	04108 14
PISHKUN WR	04108 15
RED ROCK LAKES WR	04108 16
THIBADEAU LAKE WR	04108 17
WILDHORSE NWR	04108 18
WILLOW CREEK WR	04108 19
RAVALLI NWR	04108 20
MOISE BISON RANGE	04108 21

NEVADA	04105 00
ANAHO ISLAND NWR	04105 01
DESERT GAME RANGE NWR	04105 02
FALLON NWR	04105 03
RUBY LAKE NWR	04105 04
CHARLES SHELDON ANTELOPE REF	04105 05
STILLWATER NWR	04105 06
WINNEMUCCA NWR	04105 07

OREGON	04102 00
CAPE MEARES NWR	04102 01
COLD SPRINGS NWR	04102 02
HART MT NAT ANTELOPE REF	04102 03
KLAMATH FOREST NWR	04102 04
MALHEUR FOREST NWR	04102 05
MCKAY CREEK NWR	04102 06
OREGON ISLANDS NWR	04102 07
THREE ARCH ROCKS NWR	04102 08
UMATILLA NWR	04102 09
UPPER KLAMATH NWR	04102 10
WILLIAM L. FINLEY NWR	04102 11

WASHINGTON	04103 00
COLOMBIA NWR	04103 01
COPALIS NWR	04103 02
DUNGENESS NWR	04103 03
FLATTERY ROCKS NWR	04103 04
JONES ISLAND NWR	04103 05
LITTLE PEND OREILLE NWR	04103 06
MATIA ISLAND NWR	04103 07
MCNARY NW MANAGEMENT AREA	04103 08
QUILLAYUTE NEEDLES NWR	04103 09
SAN JUAN NWR	04103 10
SMITH ISLAND NWR	04103 11
TWIN BULL NWR	04103 12
WILLAPA NWR	04103 13

REGION 2	04200 00

ARIZONA	04207 00
CABEZA PRIETA GAME RANGE	04207 01
HAVASU LAKE NWR	04207 02
KOFA GAME REFUGE	04207 03
SALT RIVER NWR	04207 04

COLORADO	04210 00
MONTE VISTA NWR	04210 01

KANSAS	04215 00
KIRWIN NAT WL MGMT AREA	04215 01
QUIVIRA NWR	04215 02
NEW MEXICO	04211 00
BITTER LAKE NWR	04211 01
BOSQUE DEL APACHE NWR	04211 02
BURFORD LAKE NWR	04211 03
SAN ANDREAS NWR	04211 04
OKLAHOMA	04216 00
SALT PLAINS NWR	04216 01
TISHOMINGO NWR	04216 02
WASHITA NWR	04216 03
WICHITA MTNS NWR	04216 04
TEXAS	04217 00
ARANSAS WA	04217 01
BUFFALO LAKES WA	04217 02
HAGERMAN WA	04217 03
LAGUNA ATASCOSA WA	04217 04
MULESHOE WA	04217 05
SANTA ANA WA	04217 06
UTAH	04206 00
BEAR R MIGRATORY BIRD REF	04206 01
FISH SPRINGS NWR	04206 02
LOCOMOTIVE SPRINGS NWR	04206 03
OURAY NWR	04206 04
WYOMING	04209 00
BAMFORTH NWR	04209 01
HUTTON LAKE NWR	04209 02
NATIONAL ELK REFUGE	04209 03
PATHFINDER NWR	04209 04

REGION 3	04300 00
IOWA	04319 00
DESOTO NWR	04319 01
MARK TWAIN NWR	04319 02
UNION SLOUGH NWR	04319 03
UPPER MISSISSIPPI R WFR	04319 04
MINNESOTA	04318 00
MILLE LACS NWR	04318 01
MUD LAKE NWR	04318 02
RICE LAKE NWR	04318 03
TAMARAC NWR	04318 04
UPPER MISSISSIPPI R NAT WFR	04318 05
MISSOURI	04320 00
MINGO NWR	04320 01
SQUAW CREEK NWR	04320 02
SWAN LAKE NWR	04320 03
NEBRASKA	04314 00
CRESCENT LAKE NWR	04314 01
FORT NIOBRARA NWR	04314 02
N. PLATTE VALLEY BIRD REF	04314 03
VALENTINE NWR	04314 04
NORTH DAKOTA	04312 00
ARROWWOOD NWR	04312 01
CHASE LAKE NWR	04312 02
DES LACS NWR	04312 03
LAKE ILO NWR	04312 04
LONG LAKE NWR	04312 05
LOSTWOOD NWR	04312 06
LOWER SOURIS NWR	04312 07
SLADE NWR	04312 08
SNAKE CREEK NWR	04312 09
SULLYS HILL NAT GAME PRES	04312 10
TEWAUKON NWR	04312 11
UPPER SOURIS NWR	04312 12
SOUTH DAKOTA	04313 00
LAKE ANDES	04313 01
BELLE FOURCHE NWR	04313 02
LA CREEK NWR	04313 03
SAND LAKE NWR	04313 04
WAUBAY NWR	04313 05

REGION 4	04400 00
ARKANSAS	04423 00
BIG LAKE NWR	04423 01
HOLLA BEND NWR	04423 02
WAPANOCCA NWR	04423 03
WHITE RIVER NWR	04423 04
LOUISIANA	04424 00
BRETON ISLANDS NWR	04424 01
CATAHOULA NWR	04424 02
DELTA NWR	04424 03
EAST TIMBALIER NWR	04424 04
LACASSINE NWR	04424 05
SABINE NWR	04424 06
SHELL KEYS NWR	04424 07

REGION 5	04500 00

REGION 6	04600 00
ALASKA	04621 00
ALEUTIAN NWR	04621 01
ARTIC NWR	04621 02
BERING SEA NWR	04621 03
BOGOSLOF NWR	04621 04
CHAMISSO NWR	04621 05
CLARENCE RHODE NWR	04621 06
FORRESTER ISLAND NWR	04621 07
HAZEN BAY NWR	04621 08
HAZY ISLAND NWR	04621 09
IZEMBEC BAY NWR	04621 10
KENAI NWR	04621 11
KODIAK NWR	04621 12
NUNIVAK NWR	04621 13
PRIBILOF ISLANDS RES NWR	04621 14
SEMIDI NWR	04621 15
SIMEONOF NWR	04621 16
ST. LAZARIA NWR	04621 17
TUXEDNI NWR	04621 18

Bureau of Land Management 41000 00

REGION 1	41100 00
CALIFORNIA ST OFF	41101 00
BAKERSFIELD OFFICE	41101 01
REDDING DIST OFF	41101 02
RIVERSIDE DIST OFF	41101 03
SUSANVILLE DIST OFF	41101 04
UKIAH DIST OFFICE	41101 05
FOLSOM DIST OFFICE	41101 06
OREGON + WASHINGTON STATE OFFICE	41102 00
BAKER DIST OFFICE	41102 01
BURNS DIST OFFICE	41102 02
COOS BAY DIST OFF	41102 03
EUGENE DIST OFFICE	41102 04
LAKEVIEW DIST OFF	41102 05
MEDFORD DIST OFF	41102 06
PRINEVILLE DIST OFF	41102 07
ROSEBURG DIST OFF	41102 08
SALEM DIST OFFICE	41102 09
SPOKANE DIST OFFICE	41102 10
VALE DIST OFFICE	41102 11
IDAHO STATE OFFICE	41103 00
BOISE DIST OFFICE	41103 01
BURLEY DIST OFFICE	41103 02
COEUR D'ALENE OFF	41103 03
IDAHO DIST OFFICE	41103 04
SALMON DIST OFFICE	41103 05
SHOSHONE DIST OFF	41103 06
NEVADA ST OFFICE	41104 00
BATTLE MTN DIST OFF	41104 01
CARSON CITY OFFICE	41104 02
ELKO DIST OFFICE	41104 03
ELY DISTRICT OFFICE	41104 04
LAS VEGAS DIST OFF	41104 05
WINNEMUCA DIST OFF	41104 06
ALASKA ST OFFICE	41105 00
ANCHORAGE DIST OFF	41105 01
FAIRBANKS DIST OFF	41105 02

REGION 2	41200 00
UTAH STATE OFFICE	41201 00
CEDAR CITY DIST OFF	41201 01
FILLMORE DIST OFF	41201 02
KANAB DIST OFFICE	41201 03
MONTICELLO DIST OFF	41201 04
PRICE DIST OFFICE	41201 05
RICHFIELD DIST OFF	41201 06
SALT LAKE DIST OFF	41201 07
VERNAL DIST OFFICE	41201 08
ARIZONA ST OFFICE	41202 00
ARIZONA STRIP OFF	41202 01
PHOENIX DIST OFFICE	41202 02
SAFFORD DIST OFFICE	41202 03
MONTANA ST OFFICE	41203 00
BILLINGS DIST OFF	41203 01
DILLON DIST OFFICE	41203 02
LEWISTOWN DIST OFF	41203 03
MALTA DIST OFFICE	41203 04
MILES CITY DIST OFF	41203 05
MISSOULA DIST OFF	41203 06
WYOMING ST OFFICE	41204 00
CASPER DIST OFFICE	41204 01
LANDER DIST OFFICE	41204 02
PINEDALE DIST OFF	41204 03
RAWLINS DIST OFFICE	41204 04
ROCK SPRINGS OFFICE	41204 05
WORLAND DIST OFFICE	41204 06
COLORADO ST OFFICE	41205 00
CANON CITY DIST OFF	41205 01
CRAIG DIST OFFICE	41205 02
GLENWOOD SPRINGS	41205 03
GRAND JUNCTION OFF	41205 04
MONTROSE DIST OFF	41205 05
NEW MEXICO ST OFFICE	41206 00
ALBUQUERQUE OFFICE	41206 01
LAS CRUCES DIST OFF	41206 02
ROSWELL DIST OFFICE	41206 03
SOCORRO DIST OFFICE	41206 04

Corps of Engineers *42000 00*

S PACIFIC DIVISION	42100 00
SAN FRANCISCO DIST	42101 00
COYOTE DAM, LAKE MENDOCINO	42101 01
SACRAMENTO DISTRICT	42102 00

N PACIFIC DIVISION	42200 00
WALLA WALLA DIST	42201 00
SEATTLE DISTRICT	42202 00
PORTLAND DISTRICT	42203 00
ANCHORAGE DISTRICT	42204 00

SOUTHWEST DIVISION	42300 00
TULSA DISTRICT	42301 00
JOHN REDMOND RES.	42301 01
FORT WORTH DISTRICT	42302 00
BENBROOK PROJECT	42302 01
WACO PROJECT	42302 02
CANYON PROJECT	42302 03
TOWNBLUFF DAM	42302 04
SAM RAYBURN PROJ	42302 05
NAVARRO HILLS PROJ	42302 06
LAVON RES	42302 07
BARDWELL RES	42302 08
HORDS CREEK RES	42302 09
DAM B RES	42302 10
WHITNEY RES	42302 11
BELTON RES	42302 12
SOMERVILLE RES	42302 13
ALBUQUERQUE DISTRICT	42303 00
GALVESTON DISTRICT	42304 00
LITTLE ROCK DISTRICT	42305 00

State Agencies

CALIFORNIA DEPT OF CONSERVATION - STATE FORESTS	
MTN HOME ST FOREST (BALCH PARK E OF PORTERVILLE IN SEQUOIA N.F.)	51200 00
LATOUR STATE FOREST (NEAR WHITMORE, E OF REDDING)	51210 00
JACKSON ST FOREST (FORT BRAGG)	51300 00
BOGGS MTN ST FOREST	51400 00
HUMBOLDT RANGER UNIT	51500 00
WHITAKER'S EXPERIMENTAL FOREST (NEAR GEN. GRANT GROVE, EAST OF FRESNO -UNDER UC BERKELEY CONTROL)	51600 00

CALIFORNIA DEPT OF TRANSPORTATION (HIGHWAYS)	51700 00

CALIFORNIA DEPT OF FISH AND GAME	51800 00
TULLOCH WILDLIFE REFUGE	51800 01

CALIFORNIA DEPT OF AGRICULTURE	51900 00

CALIFORNIA DEPT PARKS AND RECREATION	52000 00

CALIFORNIA STATE PARKS - ALPHABETIC	52000 00
ADMIRAL WILLIAM STANDLEY	52232 00
ANDREW MOLERA SP	52435 00
ANGEL ISLAND SP	52201 00
ANNADEL SP	52233 00
ANO NUEVO SR	52429 00
ANZA BORREGO DESERT	52601 00
ARMSTRONG RDWDS SR	52202 00
ASILOMAR SB	52430 00
ATASCADERO ST BEACH	52501 00
AUSTIN CREEK SRA	52203 00
AZALEA SR	52117 00
BASIN (BIG) RDWDS SP	52401 00
BENBOW LAKE SRA	52114 00
BENICIA CAPITOL SHM	52204 00

BENICIA SRA	52205	00
BIDWELL MANSION SHP	52301	00
BIG BASIN RDWDS SP	52401	00
BIG SUR (PFEIFFER) SP	52414	00
BLISS (D.L.) ST PARK	52307	00
BODIE SHP	52302	00
BOLSA CHICA ST BEACH	52605	00
BORREGA (ANZA) DESERT	52601	00
BOTHE-NAPA VALLEY SP	52206	00
BRANNAN ISLAND SRA	52303	00
BRIDGES (NATURAL) SB	52406	00
BURNS (JULIA PFEIFFER)	52421	00
BUTANO STATE PARK	52402	00
CALAVERAS BIG TREES	52304	00
CAMILLUS NELSON HISTORIC FARM	52332	00
CAPITAN (EL) ST BEACH	52503	00
CAPITOLA STATE BEACH	52404	00
CARMEL RIVER SB	52431	00
CARPINTERIA ST BEACH	52502	00
CARRILLO (LEO) ST BEACH	52510	00
CASTLE CRAGS SP	52105	00
CASTLE ROCK ST PARK	52419	00
CASWELL MEMORIAL SP	52305	00
CHICA (BOLSA) ST BEACH	52605	00
CLEAR LAKE SP	52207	00
COCHES (LOS) RANCHO SHM	52422	00
COE (HENRY W.) ST PARK	52411	00
COLUMBIA SHP	52322	00
COLUSA-SACRAMENTO RIVER SRA	52306	00
CONTRA COSTA RIDING + HIKING TRAILS	52424	00
COWELL (HENRY) RDWDS	52412	00
CRAGS (CASTLE) ST PARK	52105	00
CUYAMACA RANCHO SP	52602	00
DEL NORTE COAST REDWOODS SP	52116	00
DIABLO (MOUNT) SP	52413	00
DIMMICK (PAUL M.) SRA	52221	00
D L BLISS ST PARK	52307	00
DOHENY STATE BEACH	52603	00
DONNER MEMORIAL SP	52309	00
DRY LAGOON SP	52118	00
EL CAPITAN ST BEACH	52503	00
EMERALD BAY SP	52308	00
EMMA WOOD ST BEACH	52504	00
ENCINOS (LOS) SHM	52521	00
FOLSOM LAKE SRA	52310	00
FORD (FREMONT) SRA	52330	00
FOREST OF NISENE MARKS SP	52428	00
FORT HUMBOLDT SHM	52101	00
FORT ROSS SHP	52208	00
FORT TEJON SHP	52516	00
FRANK'S TRACT SRA	52323	00
FREMONT FORD SRA	52330	00
FREMONT PEAK ST PARK	52425	00
GAVIOTA STATE PARK	52518	00
GEORGE J HATFIELD RA	52311	00
GOVENOR'S MANSION	52326	00
GRINDING ROCK (INDIAN) SHM	52329	00
GRIZZLY CRK RDWDS SP	52106	00
GROVER HOT SPRINGS SP	52312	00
HATFIELD (GEORGE J) RA	52311	00
HEARST SAN SIMEON HM	52509	00
HEART BAR STATE PARK	52604	00
HENDY WOODS ST PARK	52209	00
HENRY W COE ST PARK	52411	00
HENRY COWELL RDWDS SP	52412	00
HUMBOLDT REDWOODS SP	52107	00
HUNTINGTON ST BEACH	52606	00
IDE (WILLIAM B.) ADOBE	52104	00
INDIAN CREEK SR	52223	00
INDIAN GRINDING ROCK SHM	52329	00
INDIAN (STATE) MUSEUM	52327	00
JACK LONDON SHP	52224	00
JEDEDIAH SMITH RDWDS	52108	00
JOHN LITTLE SR	52420	00
JOSHUA TREES ST PARK	52507	00
JULIA PFEIFFER BURNS	52421	00
KRUSE RHODODENDRON SR	52227	00
LAKE ELSINORE SRA	52607	00
LA PURISIMA MISSION	52519	00
LEO CARRILLO S BEACH	52510	00
LITTLE (JOHN) SR	52420	00
LITTLE RIVER SB	52119	00
LONDON (JACK) SHP	52224	00
LOS COCHES RANCHO HM	52422	00
LOS ENCINOS SHM	52521	00
LUMMIS HOME SHM	52524	00
MACKERRICHER SP	52210	00
MAILLIARD REDWOODS SR	52228	00
MALAKOFF DIGGINS SHP	52313	00
MALIBU CREEK SP	52529	00
MANCHESTER ST BEACH	52211	00
MANRESA STATE BEACH	52405	00
MARIN HEADLANDS SP	52432	00
MARSHALL GOLD DISCOVERY SHP	52324	00
MCARTHUR-BURNEY FALLS MEMORIAL SP	52109	00
MCCONNELL SRA	52314	00
MCGRATH ST BEACH	52505	00
MILLERTON LAKE SRA	52325	00
MITCHELL CAVERNS SR	52608	00
MONTANA DE ORO SP	52512	00
MONTEREY SHM	52423	00
MONTGOMERY WOODS SR	52229	00
MORRO BAY STATE PARK	52513	00
MOUNT DIABLO SP	52413	00
MT SAINT HELENA SP	52226	00
MT SAN JACINTO SP	52609	00
MOUNT TAMALPAIS SP	52222	00
NATURAL BRIDGES SB	52406	00
NEW BRIGHTON SB	52408	00
NISENE (FOREST OF) MARKS SP	52428	00
NUEVO, (ANO) SR	52429	00
OLD SACRAMENTO SHP	52331	00
OLD TOWN SAN DIEGO	52616	00
OROVILLE RESERVOIR	52315	00
PALACE OF FINE ARTS SHM	52434	00
PALOMAR MOUNTAIN SP	52610	00
PATRICK'S POINT SP	52110	00
PAUL M DIMMICK SRA	52221	00
PELICAN SB	52120	00
PETALUMA ADOBE SHM	52212	00
PFEIFFER BIG SUR SP	52414	00
PFEIFFER BURNS (JULIA)	52421	00
PICACHO ST REC AREA	52617	00
PIO PICO SHM	52522	00
PISMO STATE BEACH	52514	00
PLUMAS-EUREKA SP	52316	00
POINT LOBOS SR	52415	00
POINT MUGU SRA	52520	00

PORTOLA STATE PARK	52416	00
PRAIRIE CRK RDWDS SP	52111	00
PRESIDIO DE SANTA BARBARA SHM	52515	00
PUEBLO DE LOS ANGELES SHM	52525	00
PURISIMA (LA) MISSION	52519	00
REFUGIO SB	52527	00
REYNOLDS RDWD FLAT SRA	52121	00
RHODODENDRON (KRUSE) SR	52227	00
RICHARDSON GROVE SP	52113	00
ROBERT LOUIS STEVENSON SP	52231	00
ROGERS (WILL) SHP	52523	00
RUSSIAN GULCH SP	52213	00
SAINT HELENA (MT) SP	52226	00
SALINAS RIVER SB	52433	00
SALT POINT ST PARK	52225	00
SALTON SEA SRA	52611	00
SAMUEL P TAYLOR SP	52214	00
SAN BUENAVENTURA SB	52506	00
SAN CLEMENTE SB	52612	00
SAN DIEGO COAST SB	52613	00
SAN FRANCISCO MARITIME SHP	52418	00
SAN JACINTO (MT) SP	52609	00
SAN JUAN BAUTISTA SP	52426	00
SAN LUIS RESERVOIR	52317	00
SAN MATEO COAST SB	52417	00
SAN MATEO RIDING + HIKING TRAILS	52427	00
SAN PASQUAL BATTLEFIELD SHM	52618	00
SAN SIMEON (HEARST) SHM	52509	00
SAN SIMEON ST BEACH	52508	00
SANTA CRUZ COAST SB	52403	00
SANTA MONICA MTNS PARK-TRIPPET R.D.	52526	00
SEACLIFF STATE BEACH	52407	00
SHASTA SHM	52102	00
SILVER STRAND SB	52614	00
SILVERWOOD LAKE SRA	52619	00
SMITH (JEDEDIAH) RDWDS	52108	00
SMITHE RDWD SB	52122	00
SONOMA ST HIST PARK	52216	00
SONOMA COAST SB	52215	00
SQUAW VALLEY SRA	52318	00
STANDISH-HICKEY SRA	52112	00
STATE INDIAN MUSEUM	52327	00
STINSON STATE BEACH	52218	00
SUGARLOAF RIDGE SP	52217	00
SUGAR PINE POINT SP	52319	00
SUNSET STATE BEACH	52409	00
SUTTER'S FORT SHP	52328	00
TAHOE STATE REC AREA	52320	00
TAMALPAIS (MOUNT) SP	52222	00
TAYLOR (SAMUEL P) SP	52214	00
TOMALES BAY ST PARK	52219	00
TOPANGA SP	52528	00
TORREY PINES SR	52615	00
TULE ELK SR	52517	00
TURLOCK LAKE SRA	52321	00
TWIN LAKES ST BEACH	52410	00
VAN DAMME STATE PARK	52220	00
WEAVERVILLE JOSS HOUSE SHM	52103	00
WESPORT-UNION LANDING SB	52230	00
WILL ROGERS SHP	52523	00
WILLIAM B IDE ADOBE	52104	00
WOOD (EMMA) ST BEACH	52504	00
WOODSON BRIDGE SRA	52115	00

CALIFORNIA STATE PARK AREAS - ALPHABETIC

ANGEL ISLAND AREA	52200 01
ANZA-BORREGO AREA	52600 01
BENICIA AREA	52200 02
BIG BASIN AREA	52400 01
BIG SUR AREA	52400 02
BODIE AREA	52300 01
BOTHE-NAPA AREA	52200 03
CALAVERAS AREA	52300 02
CARPINTERIA AREA	52500 01
CASTLE CRAGS AREA	52100 01
CLEAR LAKE AREA	52200 04
COE (HENRY) AREA	52400 03
COLUMBIA AREA	52300 03
DELTA AREA	52300 04
DIABLO (MOUNT) AREA	52400 05
DYERVILLE AREA	52100 02
FEATHER RIVER AREA	52300 05
FOLSOM AREA	52300 06
FORT HUMBOLDT AREA	52100 03
FORT ROSS AREA	52200 05
FORT TEJON AREA	52500 02
FOUR RIVERS AREA	52300 07
FRONTERA AREA	52600 02
GAVIOTA AREA	52500 03
GROVER AREA	52300 08
HEART BAR AREA	52600 03
HENRY COE AREA	52400 03
HIOUCHI AREA	52100 04
JOSHUA TREES AREA	52500 04
LA PURISIMA MISSION	52500 05
LAKE ELSINORE AREA	52600 04
MALAKOFF DIGGINS AR	52300 09
MARIN AREA	52200 06
MARSHALL GOLD AREA	52300 01
MENDOCINO AREA	52200 07
MILLERTON-LAKE AREA	52300 11
MITCHELL CAVERNS AR	52600 05
MONTANE AREA	52600 06
MONTEREY AREA	52400 04
MORRO BAY AREA	52500 06
MOUNT DIABLO AREA	52400 05
MT SAN JACINTO AREA	52600 07
ORANGE COAST AREA	52600 08
PICACHO AREA	52600 09
PIERCY AREA	52100 06
PISMO AREA	52500 07
PLUMAS-EUREKA AREA	52300 12
POINT LOBOS AREA	52400 06
POINT MUGU AREA	52500 08
PURISIMA (LA) MISS.	52500 05
ROGERS (WILL) AREA	52500 11
RUSSIAN RIVER AREA	52200 08
SACRAMENTO AREA	52300 13
SAN DIEGO AREA	52600 11
SAN JACINTO (MT) AR	52600 07
SAN JUAN BATISTA AR	52400 07
SAN MATEO COAST AR	52400 08
SAN SIMEON AREA	52500 09
SANTA CRUZ COAST AR	52400 09
SHASTA AREA	52100 07
SIERRA AREA	52300 14
SONOMA AREA	52200 09
TEHAMA AREA	52100 08
TRINIDAD AREA	52100 09
VENTURA BEACHES AR	52500 10
WEAVERVILLE JOSS	52100 10
HOUSE AREA	52100 10
WILL ROGERS AREA	52500 11

CALIFORNIA DEPT PARKS AND RECREATION BY DISTRICT	52000	00
STATE PARKS AND AREAS		
DISTRICT 1	52100	00
CASTLE CRAGS AREA	52100	01
DYERVILLE AREA	52100	02
FORT HUMBOLDT AREA	52100	03
HIOUCHI AREA	52100	04
PIERCY AREA	52100	06
SHASTA AREA	52100	07
TEHAMA AREA	52100	08
TRINIDAD AREA	52100	09
WEAVERVILLE JOSS -HOUSE AREA	52100	10
FORT HUMBOLDT SHM	52101	00
SHASTA SHM	52102	00
WEAVERVILLE JOSS HOUSE SHM	52103	00
WILLIAM B IDE ADOBE	52104	00
CASTLE CRAGS SP	52105	00
GRIZZLY CRK RDWDS SP	52106	00
HUMBOLDT REDWOODS SP	52107	00
JEDEDIAH SMITH RDWDS	52108	00
MCARTHUR-BURNEY FALLS SP	52109	00
PATRICK'S POINT SP	52110	00
PRAIRIE CRK RDWDS SP	52111	00
STANDISH-HICKEY SRA	52112	00
RICHARDSON GROVE SP	52113	00
BENBOW LAKE SRA	52114	00
WOODSON BRIDGE SRA	52115	00
DEL NORTE COAST REDWOODS SP	52116	00
AZALEA SR	52117	00
DRY LAGOON SP	52118	00
LITTLE RIVER SB	52119	00
PELICAN SB	52120	00
REYNOLDS RDWD FLAT SRA	52121	00
SMITHE RDWD SB	52122	00

DISTRICT 2	52200	00
ANGEL ISLAND AREA	52200	01
BENICIA AREA	52200	02
BOTHE-NAPA AREA	52200	03
CLEAR LAKE AREA	52200	04
FORT ROSS AREA	52200	05
MARIN AREA	52200	06
MENDOCINO AREA	52200	07
RUSSIAN RIVER AREA	52200	08
SONOMA AREA	52200	09
ANGEL ISLAND SP	52201	00
ARMSTRONG RDWDS SR	52202	00
AUSTIN CREEK SRA	52203	00
BENICIA CAPITOL SHM	52204	00
BENICIA SRA	52205	00
BOTHE-NAPA VALLEY SP	52206	00
CLEAR LAKE SP	52207	00
FORT ROSS SHP	52208	00
HENDY WOODS ST PARK	52209	00
MACKERRICHER SP	52210	00
MANCHESTER ST BEACH	52211	00
PETALUMA ADOBE SHM	52212	00
RUSSIAN GULCH SP	52213	00
SAMUEL P TAYLOR SP	52214	00
SONOMA COAST SB	52215	00
SONOMA ST HIST PARK	52216	00
SUGARLOAF RIDGE SP	52217	00
STINSON STATE BEACH	52218	00
TOMALES BAY ST PARK	52219	00
VAN DAMME STATE PARK	52220	00
PAUL M DIMMICK SRA	52221	00
MOUNT TAMALPAIS SP	52222	00
INDIAN CREEK SR	52223	00
JACK LONDON SHP	52224	00
SALT POINT ST PARK	52225	00
MT SAINT HELENA SP	52226	00
KRUSE RHODODENDRON SR	52227	00
MAILLIARD REDWOODS SR	52228	00
MONTGOMERY WOODS SR	52229	00
WESPORT-UNION LANDING SB	52230	00
ROBERT LOUIS STEVENSON SP	52231	00
ADMIRAL WILLIAM STANDLEY	52232	00
ANNADEL SP	52233	00

DISTRICT 3	52300 00
BODIE AREA	52300 01
MARSHALL GOLD AREA	52300 01
CALAVERAS AREA	52300 02
COLUMBIA AREA	52300 03
DELTA AREA	52300 04
FEATHER RIVER AREA	52300 05
FOLSOM AREA	52300 06
FOUR RIVERS AREA	52300 07
GROVER AREA	52300 08
MALAKOFF DIGGINS AR	52300 09
MILLERTON-LAKE AREA	52300 11
PLUMAS-EUREKA AREA	52300 12
SACRAMENTO AREA	52300 13
SIERRA AREA	52300 14
BIDWELL MANSION SHP	52301 00
BODIE SHP	52302 00
BRANNAN ISLAND SRA	52303 00
CALAVERAS BIG TREES	52304 00
CASWELL MEMORIAL SP	52305 00
COLUSA-SACRAMENTO RIV SRA	52306 00
D L BLISS ST PARK	52307 00
EMERALD BAY SP	52308 00
DONNER MEMORIAL SP	52309 00
FOLSOM LAKE SRA	52310 00
GEORGE J HATFIELD RA	52311 00
GROVER HOT SPRINGS SP	52312 00
MALAKOFF DIGGINS SHP	52313 00
MCCONNELL SRA	52314 00
OROVILLE RESERVOIR	52315 00
PLUMAS-EUREKA SP	52316 00
SAN LUIS RESERVOIR	52317 00
SQUAW VALLEY SRA	52318 00
SUGAR PINE POINT SP	52319 00
TAHOE STATE REC AREA	52320 00
TURLOCK LAKE SRA	52321 00
COLUMBIA SHP	52322 00
FRANK'S TRACT SRA	52323 00
MARSHALL GOLD DISCOV SHP	52324 00
MILLERTON LAKE SRA	52325 00
GOVERNOR'S MANSION	52326 00
STATE INDIAN MUSEUM	52327 00
SUTTER'S FORT SHM	52328 00
INDIAN GRINDING ROCK SHM	52329 00
FREMONT FORD SRA	52330 00
OLD SACRAMENTO SHP	52331 00
CAMILLUS NELSON HIST FARM	52332 00

DISTRICT 4	52400 00
BIG BASIN AREA	52400 01
BIG SUR AREA	52400 02
HENRY COE AREA	52400 03
MONTEREY AREA	52400 04
MOUNT DIABLO AREA	52400 05
POINT LOBOS AREA	52400 06
SAN JUAN BATISTA AR	52400 07
SAN MATEO COAST AR	52400 08
SANTA CRUZ COAST AR	52400 09
BIG BASIN RDWDS SP	52401 00
BUTANO STATE PARK	52402 00
SANTA CRUZ COAST SB	52403 00
CAPITOLA STATE BEACH	52404 00
MANRESA STATE BEACH	52405 00
NATURAL BRIDGES SB	52406 00
SEACLIFF STATE BEACH	52407 00
NEW BRIGHTON SB	52408 00
SUNSET STATE BEACH	52409 00
TWIN LAKES ST BEACH	52410 00
HENRY W COE ST PARK	52411 00
HENRY COWELL RDWDS	52412 00
MOUNT DIABLO SP	52413 00
PFEIFFER BIG SUR SP	52414 00
POINT LOBOS SR	52415 00
PORTOLA STATE PARK	52416 00
SAN MATEO COAST SB	52417 00
SAN FRANCISCO MARITIME SHP	52418 00
CASTLE ROCK ST PARK	52419 00
JOHN LITTLE SR	52420 00
JULIA PFEIFFER BURNS SP	52421 00
LOS COCHES RANCHO HM	52422 00
MONTEREY SHM	52423 00
CONTRA COSTA RIDING + HIKING TRAILS	52424 00
FREMONT PEAK ST PARK	52425 00
SAN JUAN BAUTISTA SP	52426 00
SAN MATEO RIDING + HIKING TRAILS	52427 00
FOREST OF NISENE MARKS SP	52428 00
ANO NUEVO SR	52429 00
ASILOMAR SB	52430 00
CARMEL RIVER SB	52431 00
MARIN HEADLANDS SP	52432 00
SALINAS RIVER SB	52433 00
PALACE OF FINE ARTS SHM	52434 00
ANDREW MOLERA SP	52435 00

DISTRICT 5	52500 00
CARPINTERIA AREA	52500 01
FORT TEJON AREA	52500 02
GAVIOTA AREA	52500 03
JOSHUA TREES AREA	52500 04
LA PURISIMA MISSION	52500 05
MORRO BAY AREA	52500 06
PISMO AREA	52500 07
POINT MUGU AREA	52500 08
SAN SIMEON AREA	52500 09
VENTURA BEACHES AR	52500 10
WILL ROGERS AREA	52500 11
ATASCADERO ST BEACH	52501 00
CARPINTERIA ST BEACH	52502 00
EL CAPITAN ST BEACH	52503 00
EMMA WOOD ST BEACH	52504 00
MCGRATH ST BEACH	52505 00
SAN BUENAVENTURA SB	52506 00
JOSHUA TREES ST PARK	52507 00
SAN SIMEON ST BEACH	52508 00
HEARST SAN SIMEON HM	52509 00
LEO CARRILLO S BEACH	52510 00
MONTANA DE ORO SP	52512 00
MORRO BAY STATE PARK	52513 00
PISMO STATE BEACH	52514 00
PRESIDIO DE SANTA BARBARA SHM	52515 00
FORT TEJON SHP	52516 00
TULE ELK SR	52517 00
GAVIOTA STATE PARK	52518 00
LA PURISIMA MISSION	52519 00
POINT MUGU SRA	52520 00
LOS ENCINOS SHM	52521 00
PIO PICO SHM	52522 00
WILL ROGERS SHP	52523 00
LUMMIS HOME SHM	52524 00
PUEBLO DE LOS ANGELES SHM	52525 00
SANTA MONICA MTNS PARK-TRIPPET R.D.	52526 00
REFUGIO SB	52527 00
TOPANGA SP	52528 00
MALIBU CREEK SP	52529 00

DISTRICT 6	52600 00
ANZA-BORREGO AREA	52600 01
FRONTERA AREA	52600 02
HEART BAR AREA	52600 03
LAKE ELSINORE AREA	52600 04
MITCHELL CAVERNS AR	52600 05
MONTANE AREA	52600 06
MT SAN JACINTO AREA	52600 07
ORANGE COAST AREA	52600 08
PICACHO AREA	52600 09
SAN DIEGO AREA	52600 11
ANZA BORREGO DESERT	52601 00
CUYAMACA RANCHO SP	52602 00
DOHENY STATE BEACH	52603 00
HEART BAR STATE PARK	52604 00
BOLSA CHICA ST BEACH	52605 00
HUNTINGTON ST BEACH	52606 00
LAKE ELSINORE SRA	52607 00
MITCHELL CAVERNS SR	52608 00
MT SAN JACINTO SP	52609 00
PALOMAR MOUNTAIN SP	52610 00
SALTON SEA SRA	52611 00
SAN CLEMENTE SB	52612 00
SAN DIEGO COAST SB	52613 00
SILVER STRAND SB	52614 00
TORREY PINES SR	52615 00
OLD TOWN SAN DIEGO	52616 00
PICACHO ST REC AREA	52617 00
SAN PASQUAL BATTLEFIELD SHM	52618 00
SILVERWOOD LAKE SRA	52619 00

COLORADO DEPT OF FISH AND GAME	51800 00

NEVADA STATE PARKS	52000 00
LAHONTAN STATE PARK	52000 02
LAKE TAHOE STATE PARK	52000 01

NEW MEXICO STATE PARKS AND RECREATION	52403 00

OREGON DEPT OF FORESTRY	51200 00
NW AREA	51200 00
TRESH FOREST PARK	51200 01

OREGON DEPT OF PARKS AND RECREATION	52000 00
DISTRICT 1	52100 00
AINSWORTH STATE PARK	52101 00
BALDOCK STATE WAYSIDE	52102 00
BALD PEAK STATE PARK	52103 00
BENSON STATE PARK	52104 00
BONNEVILLE STATE PARK	52105 00
BRADLEY WAYSIDE	52106 00
CAPE LOOK OUT STATE PARK	52107 00
CAPE MEARES STATE PARK	52108 00
CHAMPOEG STATE PARK	52109 00
CROWN POINT STATE PARK	52110 00
DABNEY STATE PARK	52111 00
ECOLA STATE PARK	52112 00
FORT STEVENS STATE PARK	52113 00
GEARHART OCEAN WAYSIDE	52114 00
GEORGE W JOSEPH STATE PARK	52115 00
GUY W TALBOT STATE PARK	52116 00
HAYSTACK HILL STATE WAYSIDE	52117 00
HUG POINT STATE PARK	52118 00
JOHN B YEON STATE PARK	52119 00
KOBERG BEACH WAYSIDE	52120 00
LANG STATE PARK	52121 00
LEWIS AND CLARK STATE PARK	52122 00
LINDSEY CREEK STATE PARK	52123 00
MARY S YOUNG STATE PARK	52124 00
MAYER STATE PARK	52125 00
MCLOUGHLIN STATE PARK	52126 00
MEMALOOSE STATE PARK	52127 00
MILO MCIVER STATE PARK	52128 00
NEHALEM BAY STATE PARK	52129 00
NESKOWIN BEACH STATE WAYSIDE	52130 00
NESTUCCA SPIT STATE PARK	52131 00
OCEANSIDE BEACH STATE WAYSIDE	52132 00
OSWALD WEST STATE PARK	52133 00
PORTLAND WOMEN'S FORUM SP	52134 00
ROCKAWAY BEACH STATE WAYSIDE	52135 00
ROOSTER ROCK STATE PARK	52136 00
SADDLE MOUNTAIN STATE PARK	52137 00
SENECA FOUTS MEMORIAL PARK	52138 00
SHEPPERD'S DELL STATE PARK	52139 00
SHERIDAN STATE PARK	52140 00
STARVATION CREEK STATE PARK	52141 00
SUNSET HIGHWAY FOREST WAYSIDE	52142 00
TOLOVANA BEACH STATE WAYSIDE	52143 00
VIENTO STATE PARK	52144 00
VINZENZ LAUSMANN MEMORIAL PK	52145 00
WILLAMETTE STONE SP	52146 00
WILSON R HIWAY FOREST WAYSIDE	52147 00
WYGANT STATE PARK	52148 00
ZIBE DIMMICK STATE PARK	52149 00

DISTRICT 2	52200 00
ALSEA BAY N BRIDGEHEAD WAYSIDE	52201 00
BEACHSIDE STATE PARK	52202 00
BEVERLY BEACH STATE PARK	52203 00
BOILER BAY WAYSIDE	52204 00
BROWNSVILLE STATE WAYSIDE	52205 00
CASCADIA STATE PARK	52206 00
'D' RIVER STATE WAYSIDE	52207 00
DEPOE BAY STATE PARK	52208 00
DETROIT LAKE STATE PARK	52209 00
DEVILS LAKE STATE PARK	52210 00
DEVILS PUNCH BOWL STATE PARK	52211 00
DRIFTWOOD BEACH STATE WAYSIDE	52212 00
ELLMAKER STATE PARK	52213 00
ERRATIC ROCK WAYSIDE	52214 00
FOGARTY CREEK STATE PARK	52215 00
GLENEDEN BEACH STATE WAYSIDE	52216 00
GOVERNOR PATTERSON MEMORIAL PK	52217 00
H B VAN DUZER FOREST CORRIDOR WAYSIDE	52218 00
HOLMAN WAYSIDE	52219 00
LINCOLN BEACH STATE WAYSIDE	52220 00
LOST CREEK STATE PARK	52221 00
MAUD WILLIAMSON STATE PARK	52222 00
NORTH SANTIAM STATE PARK	52223 00
ONA BEACH STATE PARK	52224 00
OTTER CREST WAYSIDE	52225 00
ROADS END BEACH STATE WAYSIDE	52226 00
ROCKY CREEK WAYSIDE	52227 00
SAN MARINE STATE WAYSIDE	52228 00
SARAH HELMICK STATE PARK	52229 00
SEAL ROCK WAYSIDE	52230 00
SILVER FALLS STATE PARK	52231 00
SODAVILLE SPRINGS STATE PARK	52232 00
SOUTH BEACH WAYSIDE	52233 00
SOUTH NEWPORT STATE PARK	52234 00
W B NELSON WAYSIDE	52235 00
WILLIAM P KEADY WAYSIDE	52236 00
YACHATS OCEAN ROAD WAYSIDE	52237 00
YACHATS STATE PARK	52238 00
YAQUINA BAY STATE PARK	52239 00

DISTRICT 3	52300 00
ALBERT H POWERS MEMORIAL PARK	52301 00
AZALEA STATE PARK	52302 00
BANDON OCEAN WAYSIDE	52303 00
BANDON STATE PARK	52304 00
BARVIEW WAYSIDE	52305 00
BATTLE ROCK WAYSIDE	52306 00
BOLON ISLAND TIDEWAYS WAYSIDE	52307 00
BUENA VISTA OCEAN WAYSIDE	52308 00
BULLARDS BEACH STATE PARK	52309 00
CAPE ARAGO STATE PARK	52310 00
CAPE SEBASTIAN STATE PARK	52311 00
CARL G WASHBURNE MEMORIAL PARK	52312 00
CARPENTERVILLE-BROOKING FOREST WAYSIDE	52313 00
COQUILLE MYRTLE GROVE STATE PK	52314 00
CONDE B MCCULLOUGH BRIDGEHEAD - WAYSIDE	52315 00
DARLINGTONIA WAYSIDE	52316 00
DEVIL'S ELBOW STATE PARK	52317 00
FLORAS LAKE STATE PARK	52318 00
GEISEL MONUMENT WAYSIDE	52319 00
GOLDEN AND SILVER FALLS SP	52320 00
HARRIS BEACH STATE PARK	52321 00
HOFFMAN MEMORIAL WAYSIDE	52322 00
HUMBUG MOUNTAIN STATE PARK	52323 00
JESSIE M. HONEYMAN MEMORIAL PK	52324 00
JOAQUIN MILLER FOREST WAYSIDE	52325 00
LOEB STATE PARK	52326 00
MARIA C. JACKSON STATE PARK	52327 00
MILLICOMA MYRTLE GROVE SP	52328 00
MURIEL O. PONSLER MEM WAYSIDE	52329 00
NEPTUNE STATE PARK	52330 00
NORWAY MYRTLE PRESERVE	52331 00
OTTER POINT STATE WAYSIDE	52332 00
PISTOL RIVER STATE PARK	52333 00
PORT ORFORD CEDAR FOREST WAYSIDE	52334 00
ROCKWOOD BEACH STATE WAYSIDE	52335 00
SAMUEL H. BOARDMAN STATE PARK	52336 00
SEVEN DEVILS STATE WAYSIDE	52337 00
SHORE ACRES STATE PARK	52338 00
SIMPSON WAYSIDE	52339 00
SUNSET BAY STATE PARK	52340 00
SWEET MYRTLE PRESERVE	52341 00
UMPQUA LIGHTHOUSE STATE PARK	52342 00
UMPQUA WAYSIDE	52343 00
WILLIAM M. TUGMAN STATE PARK	52344 00
WINCHUCK WAYSIDE	52345 00
YOAKAM POINT STATE WAYSIDE	52346 00

DISTRICT 4	52400 00
BOOTH WAYSIDE	52401 00
CHANDLER WAYSIDE	52402 00
CLINE FALLS STATE PARK	52403 00
COLLIER MEMORIAL STATE PARK	52404 00
DESCHUTES RIVER STATE PARK	52405 00
ELLIOTT R. CORBETT II MEM PARK	52406 00
FORT ROCK STATE MONUMENT	52407 00
GOOSE LAKE STATE REC AREA	52408 00
JACKSON F. KIMBALL STATE PARK	52409 00
KLAMATH FALLS-LAKEVIEW FOREST WAYSIDE	52410 00
LAPINE STATE RECREATION AREA	52411 00
LAVA RIVER CAVES STATE PARK	52412 00
OCHOCO LAKE STATE PARK	52413 00
OCHOCO WAYSIDE	52414 00
PAINTED HILLS STATE PARK	52415 00
PETER SKENE OGDEN SCENIC WAYSIDE	52416 00
PILOT BUTTE STATE PARK	52417 00
PRINEVILLE RESERVOIR STATE PARK	52418 00
REDMOND-BEND JUNIPER WAYSIDE	52419 00
ROBERT W. SAWYER STATE PARK	52420 00
SISTERS STATE PARK	52421 00
SMITH ROCK STATE PARK	52422 00
THE COVE PALISADES STATE PARK	52423 00
TUMALO STATE PARK	52424 00

DISTRICT 5	52500 00
BATTLE MOUNTAIN STATE PARK	52501 00
CATHERINE CREEK STATE PARK	52502 00
CLARNO STATE PARK	52503 00
DYER WAYSIDE	52504 00
EMIGRANT SPRINGS STATE PARK	52505 00
FAREWELL BEND STATE PARK	52506 00
HAT ROCK STATE PARK	52507 00
HILGARD JUNCTION STATE PARK	52508 00
LAKE OWYHEE STATE PARK	52509 00
ONTARIO STATE PARK	52510 00
RED BRIDGE STATE PARK	52511 00
SHELTON WAYSIDE	52512 00
UKIAH-DALE FOREST WAYSIDE	52513 00
UNITY LAKE STATE PARK	52514 00
WALLOWA LAKE STATE PARK	52515 00
ARLINGTON WAYSIDE	52516 00
BATTLE MOUNTAIN FOREST WAYSIDE	52517 00
BLUE MOUNTAIN FOREST WAYSIDE	52518 00
GANGLOFF WAYSIDE	52519 00
J. S. BURRES STATE PARK	52520 00
LITTLE SHEEP CREEK STATE WAYSIDE	52521 00
MINAM STATE REC AREA	52522 00
SUCCOR CREEK STATE REC AREA	52523 00
THOMAS CONDON-JOHN DAY FOSSIL BEDS ST PK	52524 00
UNITY FOREST WAYSIDE	52525 00
WALLOWA LAKE HIGHWAY FOREST WAYSIDE	52526 00

DISTRICT 6	52600 00
ALDERWOOD WAYSIDE	52601 00
ARMITAGE STATE PARK	52602 00
BEN HUR LAMPMAN WAYSIDE	52603 00
BEN AND KEY DORRIS STATE PARK	52604 00
BLACHLY MOUNTAIN FOREST WAYSIDE	52605 00
CAMAS MOUNTAIN WAYSIDE	52606 00
CANYON CREEK FOREST WAYSIDE	52607 00
CASEY STATE PARK	52608 00
COW CREEK STATE PARK	52609 00
ELK CREEK TUNNEL FOREST WAYSIDE	52610 00
EVERGREEN RANCH WAYSIDE	52611 00
FERN RIDGE STATE PARK	52612 00
GATEWAY STATE WAYSIDE	52613 00
HENDRICKS BRIDGE WAYSIDE	52614 00
HOWARD J. MORTON MEMORIAL PARK	52615 00
HUTCHINSON WAYSIDE	52616 00
ILLINOIS RIVER STATE PARK	52617 00
JENNIE B. HARRIS WAYSIDE	52618 00
LAURELHURST STATE PARK	52619 00
MACKIN GULCH FOREST WAYSIDE	52620 00
MCLEOD WAYSIDE	52621 00
PASS CREEK WAYSIDE	52622 00
PROSPECT WAYSIDE	52623 00
RICE HILL WAYSIDE	52624 00
ROGUE RIVER FOREST WAYSIDE	52625 00
ROGUE RIVER OVERLOOK WAYSIDE	52626 00
ROSEBURG STATE PARK	52627 00
ROUGH AND READY WAYSIDE	52628 00
STAGE COACH FOREST WAYSIDE	52629 00
SUSAN CREEK STATE PARK	52630 00
TOUVELLE STATE PARK	52631 00
TUBB SPRINGS WAYSIDE	52632 00
UMPQUA MYRTLE PRESERVE	52633 00
VALLEY OF THE ROGUE STATE PARK	52634 00
WASHBURNE WAYSIDE	52635 00

UTAH DEPT OF PARKS AND RECREATION	52000 00
PALISADE STATE PARK	52001 00

WASHINGTON DEPT OF NATURAL RESOURCES	51200 00

WASHINGTON DEPT OF PARKS AND RECREATION	52000 00

WASHINGTON STATE PARKS

SOUTHWEST REGION	52100 00
BEACON ROCK	52101 00
BUSH PACIFIC	52102 00
FORT CANBY	52103 00
FORT COLUMBIA	52104 00
JACKSON HOUSE	52105 00
JONES BEACH	52106 00
LAKE SYLVIA	52107 00
LEADBETTER POINT	52108 00
LEWIS AND CLARK	52109 00
LEWIS AND CLARK CAMPSITE	52110 00
MATILDA JACKSON	52111 00
MAYFIELD LAKE	52112 00
MILLERSYLVANIA	52113 00
MONTICELLO CONVEN MONUMENT	52114 00
OCEAN CITY	52115 00
PARADISE POINT	52116 00
RAINBOW FALLS	52117 00
SCHAFER	52118 00
SEAQUEST	52119 00
TWIN HARBORS	52120 00
WILLIE KEIL'S GRAVE	52121 00
WORMALD	52122 00
BATTLE GROUND LAKE	52123 00
IKE KINSWA	52124 00

OLYMPIC PEN. + PUGET SOUND REGION	52200 00
BELFAIR	52201 00
BLAKE ISLAND	52202 00
BOGACHIEL	52203 00
BRIDLE TRAILS	52204 00
CAPTAIN WALLACE'S GRAVE	52205 00
CHIEF SEATTLE'S GRAVE	52206 00
DASH POINT	52207 00
DOSEWALLIPS	52208 00
DUNGENESS	52209 00
EAGLE ISLAND	52210 00
FAY-BAINBRIDGE	52211 00
FEDERATION FOREST	52212 00
FORT FLAGLER	52213 00
FORT WARD	52214 00
FORT WORDEN	52215 00
GRAVEYARD SPIT	52216 00
ILLAHEE	52217 00
JARRELL COVE	52218 00
KITSAP MEMORIAL	52219 00
KOPACHUCK	52220 00
LAKE CUSHMAN	52221 00
LAKE SAMMAMISH	52222 00
MAHLER	52223 00
OLD FORT TOWNSEND	52224 00
OLD MAN HOUSE	52225 00
PENROSE POINT	52226 00
PLEASANT HARBOR	52227 00
POTLATCH	52228 00
RIGNEY	52229 00
ROTHSCHILD HOUSE	52230 00
SALTWATER	52231 00
SCENIC BEACH	52232 00
SEQUIM BAY	52233 00
SQUAXIN ISLAND	52234 00
TWANOH	52235 00
TWIN FALLS	52236 00
TOLMIE	52237 00

NORTHWEST REGION	52300 00
BAYVIEW	52301 00
BIRCH BAY	52302 00
CAMANO ISLAND	52303 00
DECEPTION PASS	52304 00
DECEPTION ISLAND	52304 00
HOPE ISLAND	52304 00
NORTHWEST ISLAND	52304 00
PASS ISLAND	52304 00
SKAGIT ISLAND	52304 00
STRAWBERRY ISLAND	52304 00
DONOVAN	52305 00
FORT CASEY	52306 00
FORT EBEY	52307 00
LARRABEE	52308 00
MOUNT PILCHUCK	52309 00
MUKILTEO	52310 00
PEACE ARCH	52311 00
ROCKPORT	52312 00
SOUTH WHIDBEY	52313 00
USELESS BAY	52314 00
WENBERG	52315 00
JONES ISLAND	52316 00
MATIA ISLAND	52317 00
MORAN	52317 00
POSEY ISLAND	52319 00
PREVOST HARBOR	52320 00
REID HARBOR	52321 00
SUCIA ISLAND	52322 00
TURN ISLAND	52323 00
BARREN ISLAND	52324 00
BATTLESHIP ISLAND	52325 00
BLACK ROCK	52326 00
CEMETERY ISLAND	52327 00
CLARK ISLAND	52328 00
DANGER ROCK	52329 00
DOE ISLAND	52330 00
DOT ROCK	52331 00
FREEMAN ISLAND	52332 00
GEORGE ISLAND	52333 00
GULL REEF	52334 00
GULL ROCK	52335 00
GUSS ISLAND	52336 00
HALFTIDE ROCKS	52337 00
HALL ISLAND	52338 00
ICEBERG ISLAND	52339 00
JAMES ISLAND	52340 00
KNOB ISLAND	52341 00
LAWSON ROCK	52342 00
LOPEZ ISLAND	52343 00
LOW ISLAND	52344 00
MOUATT REEF	52346 00
MUMMY ROCKS	52347 00
NORTH PACIFIC ROCK	52348 00
NORTH PEAPOD	52349 00
OLGA	52350 00
PARKER REEF	52351 00
PEAPOD ROCKS	52352 00
POINTER ISLAND	52353 00
RIPPLE ISLAND	52354 00
ROCK ISLAND	52355 00
SECAR ROCK	52356 00
SHAG ROCK	52357 00
SISTERS, THE	52358 00
SKIPJACK ISLAND	52359 00
SKULL ISLAND	52360 00
SOUTH PEAPOD	52361 00
UNNAMED ISLAND	52362 00
VICTIM ISLAND	52363 00
WASP ISLAND	52364 00
WHITE ROCK	52365 00
SPENCER SPIT	52366 00

NORTH CENTRAL + NE REGION	52400 00
ALTA LAKE	52401 00
BRIDGEPORT	52402 00
CHIEF JOSEPH	52403 00
CONCONULLY	52404 00
CRAWFORD CAVE	52405 00
CROWN POINT	52406 00
CURLEW LAKE	52407 00
DRY FALLS	52408 00
FORT OKANOGAN	52409 00
ICE CAVE	52410 00
INDIAN ROCK PAINTINGS	52411 00
LAKE CHELAN	52412 00
LAKE LENORE CAVES	52413 00
LAKE NEWPORT	52414 00
LAKE WENATCHEE	52415 00
MOUNT SPOKANE	52416 00
OSOYOOS LAKE	52417 00
PEARRYGIN LAKE	52418 00
PEND OREILLE	52419 00
RANALD MACDONALD'S GRAVE	52420 00
RIVERSIDE	52421 00
ROCK ISLAND	52422 00
ST. PAUL'S MISSION	52423 00
SPOKANE HOUSE	52424 00
SPOKANE PLAINS BATTLEFIELD	52425 00
SQUILLCHUCK	52426 00
STEAMBOAT ROCK	52427 00
SUMMER FALLS	52428 00
SUN LAKES	52429 00

SOUTH CENTRAL + SE REGION	52500 00
BROOKS MEMORIAL	52501 00
CAMP WOOTEN	52502 00
CROW BUTTE	52503 00
FIELDS' SPRING	52504 00
FORT SIMCOE	52505 00
GINKGO	52506 00
HORSETHIEF LAKE	52507 00
INDIAN ROCK PAINTINGS	52508 00
KAMIAK BUTTE	52509 00
LAKE EASTON	52510 00
LEWIS AND CLARK TRAIL	52511 00
MOSES LAKE	52512 00
PALOUSE FALLS	52513 00
POTHOLES RESERVOIR	52514 00
SACAJAWEA	52515 00
STEPTOE BATTLEFIELD	52516 00
STEPTOE BUTTE	52517 00
WANAPUM	52518 00
YAKIMA	52519 00

OTHER AGENCIES (STATE)	58000 00

Public Utilities 60000 00- 69900 00

PACIFIC GAS AND ELECTRIC	61000 001
SO. CALIF. EDISON	62000 001
EAST BAY WATER	63000 001
ALL MUNICIPAL UTILITIES (INCLUDE CITY CODE)	64000 00
CASITAS MUNICIPAL WATER DIST.,OJAI,CA	64025 30

Regional, County, and City Agencies 70000 00

DIV OF FORESTRY (CITY OR COUNTY)	70100 00
PARKS AND RECREATION (CITY OR COUNTY)	70100 00
PARKS AND RECREATION(REGION)	
PRIVATE PROPERTY	70100 001
PUBLIC WORKS - TREE	70400 00
DIVISION (CITY OR COUNTY)	70700 00

Soil Conservation Service 77000 00

Bureau of Reclamation 80000 00

REGION 1	80100 00
COLUMBIA-N PACIFIC PLANNING OFFICE	80101 00
REGION 2	80200 00
REGION 3	80300 00
REGION 4	80400 00
GRAND JCT PROJ COL	80404 00
PROVO PROJ UTAH	80405 00
DURANGO PROJ COL	80406 00
REGION 5	80500 00
REGION 6	80600 00
REGION 7	80700 00
MISSOURI RIVER BASIN PLANNING OFFICE	80701 00
ALASKA DISTRICT	80800 00

STATE AND COUNTY CODES

State and County codes were assigned before the GSA *Worldwide Geographic Location Codes* became available. They may be changed, if desired, by agencies maintaining their own records. The codes used here are generally arranged in alphabetic order by State and by County within State.

General

ALABAMA	24	NEBRASKA	14
ALASKA	21	NEVADA	05
ARIZONA	07	NEW HAMPSHIRE	38
ARKANSAS	23	NEW JERSEY	39
CALIFORNIA	01	NEW MEXICO	11
COLORADO	10	NEW YORK	40
CONNECTICUT	25	NORTH CAROLINA	41
DELAWARE	26	NORTH DAKOTA	12
FLORIDA	27	OHIO	42
GEORGIA	28	OKLAHOMA	16
HAWAII	22	OREGON	02
IDAHO	04	PENNSYLVANIA	43
ILLINOIS	29	PUERTO RICO	51
INDIANA	30	RHODE ISLAND	44
IOWA	19	SOUTH CAROLINA	45
KANSAS	15	SOUTH DAKOTA	13
KENTUCKY	31	TENNESSEE	46
LOUISIANA	35	TEXAS	17
MAINE	32	UTAH	06
MARYLAND	33	VERMONT	47
MASSACHUSETTS	34	VIRGINIA	48
MICHIGAN	36	WASHINGTON	03
MINNESOTA	18	WEST VIRGINIA	49
MISSISSIPPI	37	WISCONSIN	50
MISSOURI	20	WYOMING	09
MONTANA	08		

Detail

ALABAMA	24000
AUTAUGA	24001
BALDWIN	24002
BARBOUR	24003
BIBB	24004
BLOUNT	24005
BULLOCK	24006
BUTLER	24007
CALHOUN	24008
CHAMBERS	24009
CHEROKEE	24010
CHILTON	24011
CHOCTAW	24012
CLARKE	24013
CLAY	24014
CLEBOURNE	24015
COFFEE	24016
COLBERT	24017
CONECUH	24018
COOSA	24019
COVINGTON	24020
CRENSHAW	24021
CULLMAN	24022
DALE	24023
DALLAS	24024
DE KALB	24025
ELMORE	24026
ESCAMBIA	24027
ETOWAH	24028
FAYETTE	24029
FRANKLIN	24030
GENEVA	24031
GREENE	24032
HALE	24033
HENRY	24034
HOUSTON	24035
JACKSON	24036
JEFFERSON	24037
LAMAR	24038
LAUDERDALE	24039
LAWRENCE	24040
LEE	24041
LIMESTONE	24042
LOWNDES	24043
MACON	24044
MADISON	24045
MARENGO	24046
MARION	24047
MARSHALL	24048
MOBILE	24049
MONROE	24050
MONTGOMERY	24051
MORGAN	24052
PERRY	24053
PICKENS	24054
PIKE	24055
RANDOLPH	24056
RUSSELL	24057
ST. CLAIR	24058
SHELBY	24059
SUMTER	24060
TALLADEGA	24061
TALLAPOOSA	24062
TUSCALOOSA	24063
WALKER	24064
WASHINGTON	24065
WASHINGTON	24065
WILCOX	24066
WINSTON	24067

ALASKA	21000
ALEUTIAN ISLANDS DIV	21010
ANCHORAGE DIVISION	21020
ANGOON DIVISION	21030
BARROW-NORTH SLOPE	21040
BETHEL DIV	21050
BRISTOL BAY BORO DIV	21060
BRISTOL BAY DIV	21070
CORDOVA-MCCARTHY DIV	21080
FAIRBANKS DIV	21090
HAINES DIV	21100
JUNEAU DIV	21110
KENAI-COOK INLET DIV	21120
KETCHIKAN DIV	21130
KOBUK DIV	21140
KODIAK DIV	21150
KUSKOKWIM DIV	21160
MATANUSKA-SUSITNA DIV	21170
NOME DIV	21180
OUTER KETCHIKAN DIV	21190
PRINCE OF WALES DIV	21200
SEWARD DIV	21210
SITKA DIV	21220
SKAGWAY-YAKUTAT DIV	21230
SO. EAST FAIRBANKS DIV	21240
UPPER YUKON DIV	21250
VALDEZ-CHITINA-WHITT DIV	21260
WADE HAMPTON DIV	21270
WRANGELL-PETERSBURG DIV	21280
YUKON-KOYUKUK DIV	21290

ARIZONA	07000
APACHE	07001
COCHISE	07002
COCONINO	07003
GILA	07004
GRAHAM	07005
GREENLEE	07006
MARICOPA	07007
MOHAVE	07008
NAVAJO	07009
PIMA	07010
PINAL	07011
SANTA CRUZ	07012
YAVAPAI	07013
YUMA	07014

ARKANSAS	23000
ARKANSAS	23001
ASHLEY	23002
BAXTER	23003
BENTON	23004
BOONE	23005
BRADLEY	23006

CALHOUN	23007
CARROLL	23008
CHICOT	23009
CLARK	23010
CLAY	23011
CLEBURNE	23012
CLEVELAND	23013
COLUMBIA	23014
CONWAY	23015
CRAIGHEAD	23016
CRAWFORD	23017
CRITTENDEN	23018
CROSS	23019
DALLAS	23020
DESHA	23021
DREW	23022
FAULKNER	23023
FRANKLIN	23024
FULTON	23025
GARLAND	23026
GRANT	23027
GREENE	23028
HEMPSTEAD	23029
HOT SPRING	23030
HOWARD	23031
INDEPENDENCE	23032
IZARD	23033
JACKSON	23034
JEFFERSON	23035
JOHNSON	23036
LAFAYETTE	23037
LAWRENCE	23038
LEE	23039
LINCOLN	23040
LITTLE RIVER	23041
LOGAN	23042
LONOKE	23043
MARION	23044
MILLER	23045
MISSISSIPPI	23046
MONROE	23047
MONTGOMERY	23048
NEWTON	23049
NEVADA	23050
OUACHITA	23051
PERRY	23052
PHILLIPS	23053
PIKE	23054
POINSETT	23055
POLK	23056
POPE	23057
PRAIRIE	23058
PULASKI	23059
RANDOLPH	23060
SALINE	23061
SCOTT	23062
SEARCY	23063
SEBASTIAN	23064
SEVIER	23065
SHARP	23066
ST. FRANCIS	23067
STONE	23068
UNION	23069
VAN BUREN	23070
WASHINGTON	23071
WHITE	23072
WOODRUFF	23073
YELL	23074

CALIFORNIA	01000
ALAMEDA	01001
ALPINE	01002
AMADOR	01003
BUTTE	01004
CALAVERAS	01005
COLUSA	01006
CONTRA COSTA	01007
DEL NORTE	01008
EL DORADO	01009
FRESNO	01010
GLENN	01011
HUMBOLDT	01012
IMPERIAL	01013
INYO	01014
KERN	01015
KINGS	01016
LAKE	01017
LASSEN	01018
LOS ANGELES	01019
MADERA	01020
MARIN	01021
MARIPOSA	01022
MENDOCINO	01023
MERCED	01024
MODOC	01025
MONO	01026
MONTEREY	01027
NAPA	01028
NEVADA	01029
ORANGE	01030
PLACER	01031
PLUMAS	01032
RIVERSIDE	01033
SACRAMENTO	01034
SAN BENITO	01035
SAN BERNARDINO	01036
SAN DIEGO	01037
SAN FRANCISCO	01038
SAN JOAQUIN	01039
SAN LUIS OBISPO	01040
SAN MATEO	01041
SANTA BARBARA	01042
SANTA CLARA	01043
SANTA CRUZ	01044
SHASTA	01045
SIERRA	01046
SISKIYOU	01047
SOLANO	01048
SONOMA	01049
STANISLAUS	01050
SUTTER	01051
TEHAMA	01052
TRINITY	01053
TULARE	01054
TUOLUMNE	01055
VENTURA	01056
YOLO	01057
YUBA	01058

COLORADO	10000
ADAMS	10001
ALAMOSA	10002
ARAPAHOE	10003
ARCHULETA	10004
BACA	10005
BENT	10006
BOULDER	10007
CHAFFEE	10008
CHEYENNE	10009
CLEAR CREEK	10010
CONEJOS	10011
COSTILLA	10012
CROWLEY	10013
CUSTER	10014
DELTA	10015
DOLORES	10016
DOUGLAS	10017
EAGLE	10018
ELBERT	10019
EL PASO	10020
FREMONT	10021
GARFIELD	10022
GILPIN	10023
GRAND	10024
GUNNISON	10025
HINSDALE	10026
HUERFANO	10027
JACKSON	10028
JEFFERSON	10029
KIOWA	10030
KIT CARSON	10031
LAKE	10032
LA PLATA	10033
LARIMER	10034
LAS ANIMAS	10035
LINCOLN	10036
LOGAN	10037
MESA	10038
MINERAL	10039
MOFFAT	10040
MONTEZUMA	10041
MONTROSE	10042
MORGAN	10043
OTERO	10044
OURAY	10045
PARK	10046
PHILLIPS	10047
PITKIN	10048
PROWERS	10049
PUEBLO	10050
RIO BLANCO	10051
RIO GRANDE	10052
ROUTT	10053
SAGUACHE	10054
SAN JUAN	10055
SAN MIGUEL	10056
SEDGWICK	10057
SUMMIT	10058
TELLER	10059
WASHINGTON	10060
WELD	10061
YUMA	10062

CONNECTICUT	25000
FAIRFIELD	25001
HARTFORD	25002
LITCHFIELD	25003
MIDDLESEX	25004
NEW HAVEN	25005
NEW LONDON	25006
TOLLAND	25007
WINDHAM	25008

DELAWARE	26000
KENT	26001
NEW CASTLE	26002
SUSSEX	26003

FLORIDA	27000
ALACHUA	27001
BAKER	27002
BAY	27003
BRADFORD	27004
BREVARD	27005
BROWARD	27006
CALHOUN	27007
CHARLOTTE	27008
CITRUS	27009
CLAY	27010
COLLIER	27011
COLUMBIA	27012
DADE	27013
DESOTO	27014
DIXIE	27015
DUVAL	27016
ESCAMBIA	27017
FLAGLER	27018
FRANKLIN	27019
GADSDEN	27020
GILCHRIST	27021
GLADES	27022
GULF	27023
HAMILTON	27024
HARDEE	27025
HENDRY	27026
HERNANDO	27027
HIGHLANDS	27028
HILLSBOROUGH	27029
HOLMES	27030
INDIAN RIVER	27031
JACKSON	27032
JEFFERSON	27033
LAFAYETTE	27034
LAKE	27035
LEE	27036
LEON	27037
LEVY	27038
LIBERTY	27039
MADISON	27040
MANATEE	27041
MARLON	27042
MARTIN	27043
MONROE	27044
NASSAU	27045
OKALOOSA	27046

OKEECHOBEE	27047
ORANGE	27048
OSCEOLA	27049
PALM BEACH	27050
PASCO	27051
PINELIAS	27052
POLK	27053
PUTNAM	27054
ST. JOHNS	27055
ST. LUCIE	27056
SANTA ROSA	27057
SARASOTA	27058
SEMINOLE	27059
SUMTER	27060
SUWANNEE	27061
TAYLOR	27062
VOLUSIA	27063
WAKULLA	27064
WALTON	27065
WASHINGTON	27066
GEORGIA	28000
APPLING	28001
ATKINSON	28002
BACON	28003
BAKER	28004
BALDWIN	28005
BANKS	28006
BARROW	28007
BARTOW	28008
BEN HILL	28009
BERRIEN	28010
BIBB	28011
BLEEKLEY	28012
BRANTLEY	28013
BROOKS	28014
BRYAN	28015
BULLOCH	28016
BURKE	28017
BUTTS	28018
CALHOUN	28019
CAMDEN	28020
CANDLER	28021
CARROLL	28022
CATOOSA	28023
CHARLTON	28024
CHATHAM	28025
CHATTAHOOCHEE	28026
CHATTOOGA	28027
CHEROKEE	28028
CLARKE	28029
CLAY	28030
CLAYTON	28031
CLINCH	28032
COBB	28033
COFFEE	28034
COLQUITT	28035
COLUMBIA	28036
COOKE	28037
COWETA	28038
CRAWFORD	28039
CRISP	28040
DADE	28041
DAWSON	28042
DECATUR	28043
DE KALB	28044
DODGE	28045
DOOLY	28046
DOUGHERTY	28047
DOUGLAS	28048
EARLY	28049
ECHOLS	28050
EFFINGHAM	28051
ELBERT	28052
EMANUEL	28053
EVANS	28054
FANNIN	28055
FAYETTE	28056
FLOYD	28057
FORSYTH	28058
FRANKLIN	28059
FULTON	28060
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LOWNDES	28092
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QULTMAN	28118
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SCHLEY	28123
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STEWART	28128
SUMTER	28129
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TAYLOR	28133
TELFAIR	28134
TERRELL	28135
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TOOMBS	28138
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TREUTLEN	28140
TROUP	28141
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TWIGGS	28143
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MAUI	22004

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OWYHEE	04036
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POWER	04038
SHOSHONE	04039
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VALLEY	04042
WASHINGTON	04043

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WAYNE	19093
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WINNEBAGO	19095
WINNESHIEK	19096
WOODBURY	19097
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WRIGHT	19099

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WALLACE	15096
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WILSON	15099
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WYANDOTTE	15101

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WOLFE	31119
WOODFORD	31120

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ASCENSION	35003
ASSUMPTION	35004
AVOYELLES	35005
BEAUREGARD	35006
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BOSSIER	35008
CADDO	35009
CALCASIEU	35010
CALDWELL	35011
CAMERON	35012
CATAHOULA	35013
CLAIBORNE	35014
CONCORDIA	35015
DE SOTO	35016
EAST BATON ROUGE	35017
EAST CARROLL	35018
EAST FELICIANA	35019
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FRANKLIN	35021
GRANT	35022
IBERIA	35023
IBERVILLE	35024
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ORLEANS	35036
OUACHITA	35037
PLAQUEMINES	35038
POINTE COUPEE	35039
RAPIDES	35040
RED RIVER	35041
RICHLAND	35042
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ST. BERNARD	35044
ST. CHARLES	35045
ST. HELENA	35046
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ST. JOHN	35048
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ST. MARTIN	35050
ST. MARY	35051
ST. TAMMANY	35052
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VERNON	35058
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WEST FELICIANA	35063
WINN	35064

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CUMBERLAND	32003
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KENNEBEC	32006
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OXFORD	32009
PENOBSCOT	32010
PISCATAQUIS	32011
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YORK	32016

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CAROLINE	33005
CARROLL	33006
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DORCHESTER	33009
FREDERICK	33010
GARRETT	33011
HARFORD	33012
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KENT	33014
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PRINCE GEORGES	33016
QUEEN ANNES	33017
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WORCESTER	34014

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TRAVERSE	18076
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WINONA	18083
WRIGHT	18084
YELLOW MEDICINE	18085

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ALCORN	37002
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ATTALA	37004
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JASPER	37031
JEFFERSON	37032
JEFFERSON DAVIS	37034
JONES	37035
KEMPER	37036
LAFAYETTE	37037
LAMAR	37038
LAUDERDALE	37039
LAWRENCE	37040
LEAKE	37041
LEE	37042
LEFLORE	37043
LINCOLN	37044
LOWNDES	37045
MADISON	37046
MARION	37047
MARSHALL	37048
MONROE	37049
MONTGOMERY	37050
NESHOBA	37051
NEWTON	37052
NOXUBEE	37053
OKTIBBEHA	37054
PANOLA	37055
PEARL RIVER	37056
PERRY	37057
PIKE	37058
PONTOTOC	37059
PRENTISS	37060
QUITMAN	37061
RANKIN	37062
SCOTT	37063
SHARKEY	37064
SIMPSON	37065
SMITH	37066
STONE	37067
SUNFLOWER	37068
TALLAHATCHIE	37069
TATE	37070
TIPAH	37071
TISHOMINGO	37072
TUNICA	37073
UNION	37074
WALTHALL	37075
WARREN	37076
WASHINGTON	37077
WAYNE	37078
WEBSTER	37079
WILKINSON	37080
WINSTON	37081
YALOBUSHA	37082
YAZOO	37083

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ADAIR	20001
ANDREW	20002
ATCHISON	20003
AUDRAIN	20004
BARRY	20005
BARTON	20006
BATES	20007
BENTON	20008
BOLLINGER	20009
BOONE	20010
BUCHANAN	20011
BUTLER	20012
CALDWELL	20013
CALLAWAY	20014
CAMDEN	20015
CAPE GIRARDEAU	20016
CARROLL	20017
CARTER	20018
CASS	20019
CEDAR	20020
CHARITON	20021
CHRISTIAN	20022
CLARK	20023
CLAY	20024
CLINTON	20025
COLE	20026
COOPER	20027
CRAWFORD	20028
DADE	20029
DALLAS	20030
DAVIESS	20031
DE KALB	20032
DENT	20033
DOUGLAS	20034
DUNKLIN	20035
FRANKLIN	20036
GASCONADE	20037
GENTRY	20038
GREENE	20039
GRUNDY	20040
HARRISON	20041
HENRY	20042
HICKORY	20043
HOLT	20044
HOWARD	20045
HOWELL	20046
IRON	20047
JACKSON	20048
JASPER	20049
JEFFERSON	20050
JOHNSON	20051
KNOX	20052
LACLEDE	20053
LAFAYETTE	20054
LAWRENCE	20055
LEWIS	20056
LINCOLN	20057
LINN	20058
LIVINGSTON	20059
MACON	20060
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MARIES	20062
MARION	20063
MCDONALD	20064
MERCER	20065
MILLER	20066
MISSISSIPPI	20067
MONITEAU	20068
MONROE	20069
MONTGOMERY	20070
MORGAN	20071
NEW MADRID	20072
NEWTON	20073
NODAWAY	20074
OREGON	20075
OSAGE	20076
OZARK	20077
PEMISCOT	20078
PERRY	20079
PETTIS	20080
PHELPS	20081
PIKE	20082
PLATTE	20083
POLK	20084
PULASKI	20085
PUTNAM	20086
RALLS	20087
RANDOLPH	20088
RAY	20089
REYNOLDS	20090
RIPLEY	20091
SALINE	20092
SCHUYLER	20093
SCOTLAND	20094
SCOTT	20095
SHANNON	20096
SHELBY	20097
ST. CHARLES	20098
ST. CLAIR	20099
STE. GENEVIEVE	20100
ST. FRANCOIS	20101
ST. LOUIS	20102
ST. LOUIS CITY	20103
STODDARD	20104
STONE	20105
SULLIVAN	20106
TANEY	20107
TEXAS	20108
VERNON	20109
WARREN	20110
WASHINGTON	20111
WAYNE	20112
WEBSTER	20113
WORTH	20114
WRIGHT	20115
MONTANA	08000
BEAVERHEAD	08001
BIG HORN	08002
BLAIN	08003
BROADWATER	08004
CARBON	08005
CARTER	08006
CASCADE	08007
CHOUTEAU	08008
CUSTER	08009

DANIELS	08010
DAWSON	08011
DEER LODGE	08012
FALLON	08013
FERGUS	08014
FLATHEAD	08015
GALLATIN	08016
GARFIELD	08017
GLACIER	08018
GOLDEN VALLEY	08019
GRANITE	08020
HILL	08021
JEFFERSON	08022
JUDITH BASIN	08023
LAKE	08024
LEWIS AND CLARK	08025
LIBERTY	08026
LINCOLN	08027
MADISON	08028
MCCONE	08029
MEAGHER	08030
MINERAL	08031
MISSOULA	08032
MUSSELSHELL	08033
PHILLIPS	08034
PONDERA	08035
POWDER RIVER	08036
POWELL	08037
PRAIRIE	08038
RAVALLI	08039
RICHLAND	08040
ROOSEVELT	08041
ROSEBUD	08042
SANDERS	08043
SILVER BOW	08044
STILLWATER	08045
SWEET GRASS	08046
TETON	08047
TOOLE	08048
TREASURE	08049
VALLEY	08050
WHEATLAND	08051
WIBAUX	08052
YELLOWSTONE	08053
PARK	08054

NEBRASKA	14000
ADAMS	14001
ANTELOPE	14002
ARTHUR	14003
BANNER	14004
BLAINE	14005
BOONE	14006
BOX BUTTE	14007
BOYD	14008
BROWN	14009
BUFFALO	14010
BURT	14011
BUTLER	14012
CASS	14013
CEDAR	14014
CHASE	14015
CHERRY	14016
CHEYENNE	14017
CLAY	14018
COLFAX	14019
CUMING	14020
CUSTER	14021
DAKOTA	14022
DAWES	14023
DAWSON	14024
DEUEL	14025
DIXON	14026
DODGE	14027
DOUGLAS	14028
DUNDY	14029
FILLMORE	14030
FRANKLIN	14031
FRONTIER	14032
FURNAS	14033
GAGE	14034
GARDEN	14035
GARFIELD	14036
GOSPER	14037
GRANT	14038
GREELY	14039
HALL	14040
HAMILTON	14041
HARLAN	14042
HAYES	14043
HITCHCOCK	14044
HOLT	14045
HOOKER	14046
HOWARD	14047
JEFFERSON	14048
JOHNSON	14049
KEARNY	14050
KEITH	14051
KEYA PAHA	14052
KIMBALL	14053
KNOX	14054
LANCASTER	14055
LOGAN	14056
LOUP	14057
MADISON	14058
MCPHERSON	14059
MERRICK	14060
MORRIL	14061
NANCE	14062
NEMAHA	14063
NUCKOLLS	14064
OTOE	14065
PAWNEE	14066
PERKINS	14067
PHELPS	14068
PIERCE	14069
PLATTE	14070
POLK	14071
RED WILLOW	14072
RICHARDSON	14073
ROCK	14074
SALINE	14075
SARPY	14076
SAUNDERS	14077
SCOTTS BLUFF	14078
SEWARD	14079
SHERIDAN	14080
SHERMAN	14081

SIOUX	14082
STANTON	14083
THAYER	14084
THOMAS	14085
THURSTON	14086
VALLEY	14087
WASHINGTON	14088
WAYNE	14089
WEBSTER	14090
WHEELER	14091

NEVADA	05000
CHURCHILL	05001
CLARK	05002
DOUGLAS	05003
ELKO	05004
ESMERELDA	05005
EUREKA	05006
HUMBOLDT	05007
LANDER	05008
LINCOLN	05009
LYON	05010
MINERAL	05011
NYE	05012
ORMSBY	05013
PERSHING	05014
STORY	05015
WASHOE	05016
WHITE PINE	05017

NEW HAMPSHIRE	38000
BELKNAP	38001
CARROLL	38002
CHESHIRE	38003
COOS	38004
GRAFTON	38005
HILLSBOROUGH	38006
MERRIMACK	38007
ROCKINGHAM	38008
STAFFORD	38009
SULLIVAN	38010

NEW JERSEY	39000
ATLANTIC	39001
BERGEN	39002
BURLINGTON	39003
CAMDEN	39004
CAPE MAY	39005
CUMBERLAND	39006
ESSEX	39007
GLOUCESTER	39008
HUDSON	39009
HUNTERDON	39010
MERCER	39011
MIDDLESEX	39012
MONMOUTH	39013
MORRIS	39014
OCEAN	39015
PASSAIC	39016
SALEM	39017
SOMERSET	39018
SUSSEX	39019
UNION	39020
WARREN	39021

NEW MEXICO	11000
BERNALILLO	11001
CATRON	11002
CHAVES	11003
COLFAX	11004
CURRY	11005
DE BACA	11006
DONA ANA	11007
EDDY	11008
GRANT	11009
GUADALUPE	11010
HARDING	11011
HIDALGO	11012
LEA	11013
LINCOLN	11014
LOS ALAMOS	11015
LUNA	11016
MCKINLEY	11017
MORA	11018
OTERO	11019
QUAY	11020
RIO ARRIBA	11021
ROOSEVELT	11022
SANDOVAL	11023
SAN JUAN	11024
SAN MIGUEL	11025
SANTA FE	11026
SIERRA	11027
SOCORRO	11028
TAOS	11029
TORRANCE	11030
UNION	11031
VALENCIA	11032

NEW YORK	40000
ALBANY	40001
ALLEGHANY	40002
BRONX	40003
BROOME	40004
CATTARAUGUS	40005
CAYUGA	40006
CHAUTAUGUA	40007
CHEMUNG	40008
CHENANGO	40009
CLINTON	40010
COLUMBIA	40011
CORTLAND	40012
DELAWARE	40013
DUTCHESS	40014
ERIE	40015
ESSEX	40016
FRANKLIN	40017
FULTON	40018
GENESSEE	40019
GREENE	40020
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HERKIMER	40022
JEFFERSON	40023
KINGS	40024
LEWIS	40025
LIVINGSTON	40026
MADISON	40027
MONROE	40028
MONTGOMERY	40029

NASSAU	40030
NEW YORK	40031
NIAGARA	40032
ONEIDA	40033
ONONDAGA	40034
ONTARIO	40035
ORANGE	40036
ORLEANS	40037
OSWEGO	40038
OTSEGO	40039
PUTNAM	40040
QUEENS	40041
RENSSELAER	40042
RICHMOND	40043
ROCKLAND	40044
ST. LAWRENCE	40045
SARATOGA	40046
SCHENECTADY	40047
SCHOHARIE	40048
SCHUYLER	40049
SENECA	40050
STEUBEN	40051
SUFFOLK	40052
SULLIVAN	40053
TIOGA	40054
TOMPKINS	40055
ULSTER	40056
WARREN	40057
WASHINGTON	40058
WAYNE	40059
WESTCHESTER	40060
WYOMING	40061
YATES	40062
NORTH CAROLINA	41000
ALAMANEE	41001
ALEXANDER	41002
ALLEGHANY	41003
ANSON	41004
ASHE	41005
AVERY	41006
BEAUFORT	41007
BERTLE	41008
BLADEN	41009
BRUNSWICK	41010
BUNCOMBE	41011
BURKE	41012
CABARRUS	41013
CALDWELL	41014
CAMDEN	41015
CARTERET	41016
CASWELL	41017
CATAWBA	41018
CHATHAM	41019
CHEROKEE	41020
CHOWAN	41021
CLAY	41022
CLEVELAND	41023
COLUMBUS	41024
CRAVEN	41025
CUMBERLAND	41026
CURRITUCK	41027
DARE	41028
DAVIDSON	41029
DAVIE	41030
DUPLIN	41031
DURHAM	41032
EDGECOMBE	41033
FORSYTH	41034
FRANKLIN	41035
GASTON	41036
GATES	41037
GRAHAM	41038
GRANVILLE	41039
GREENE	41040
GUILFORD	41041
HALIFAX	41042
HARNETT	41043
HAYWOOD	41044
HENDERSON	41045
HERTFORD	41046
HOKE	41047
HYDE	41048
IREDELL	41049
JACKSON	41050
JOHNSTON	41051
JONES	41052
LEE	41053
LENOIR	41054
LINCOLN	41055
MCDOWELL	41056
MACON	41057
MADISON	41058
MARTIN	41059
MECKLENBURG	41060
MITCHELL	41061
MONTGOMERY	41062
MOORE	41063
NASH	41064
NEW HANOVER	41065
NORTHAMPTON	41066
ONSLOW	41067
ORANGE	41068
PAMLICO	41069
PASQUOTANK	41070
PENDER	41071
PERQUIMANS	41072
PERSON	41073
PITT	41074
POLK	41075
RANDOLPH	41076
RICHMOND	41077
ROVESON	41078
ROCKINGHAM	41079
ROWAN	41080
RUTHERFORD	41081
SAMPSON	41082
SANLY	41083
SCOTLAND	41084
STOKES	41085
SURRY	41086
SWAIN	41087
TRANSYLVANIA	41088
TYRRELL	41089
UNION	41090
VANCE	41091
WAKE	41092
WARREN	41093
WASHINGTON	41094

WATAUGE	41095
WAYNE	41096
WILKES	41097
WILSON	41098
YADKIN	41099
YANCEY	41100

NORTH DAKOTA	12000
ADAMS	12001
BARNES	12002
BENSON	12003
BILLINGS	12004
BOTTINEAU	12005
BOWMAN	12006
BURKE	12007
BURLEIGH	12008
CASS	12009
CAVALIER	12010
DICKEY	12011
DIVIDE	12012
DUNN	12013
EDDY	12014
EMMONS	12015
FOSTER	12016
GOLDEN VALLEY	12017
GRAND FORKS	12018
GRANT	12019
GRIGGS	12020
HETTINGER	12021
KIDDER	12022
LA MOURE	12023
LOGAN	12024
MCHENRY	12025
MCINTOSH	12026
MCKENZIE	12027
MCLEAN	12028
MORTON	12029
MOUNTRAIL	12030
NELSON	12031
OLIVER	12032
PEMBINA	12033
PIERCE	12034
RAMSEY	12035
RANSOM	12036
RENVILLE	12037
RICHLAND	12038
ROLETTE	12039
SARGENT	12040
SHERIDAN	12041
SIOUX	12042
SLOPE	12043
STARK	12044
STEELE	12045
STUTSMAN	12046
TOWNER	12047
TRAILL	12048
WALSH	12049
WELLS	12050
WILLIAMS	12051

OHIO	42000
ADAMS	42001
ALLEN	42002
ASHLAND	42003
ASHTABULA	42004
ATHENS	42005
AUGLAIZE	42006
BELMONT	42007
BROWN	42008
BUTLER	42009
CARROLL	42010
CHAMPAIGN	42011
CLARK	42012
CLERMONT	42013
CLINTON	42014
COLUMBIANA	42015
COSHOCTON	42016
CRAWFORD	42017
CUYAHOGA	42018
DARKE	42019
DEFIANCE	42020
DELAWARE	42021
ERIE	42022
FAIRFIELD	42023
FAYETTE	42024
FRANKLIN	42025
FULTON	42026
GALLIA	42027
GEAUGA	42028
GREENE	42029
GUERNSEY	42030
HAMILTON	42031
HANCOCK	42032
HARDIN	42033
HARRISON	42034
HENRY	42035
HIGHLAND	42036
HOCKING	42037
HOLMES	42038
HURON	42039
JACKSON	42040
JEFFERSON	42041
KNOX	42042
LAKE	42043
LAWRENCE	42044
LICKING	42045
LOGAN	42046
LORAIN	42047
LUCAS	42048
MADISON	42049
MAHONING	42050
MARION	42051
MEDINA	42052
MEIGS	42053
MERCER	42054
MIAMI	42055
MONROE	42056
MONTGOMERY	42057
MORGAN	42058
MORROW	42059
MUSKINGUM	42060
NOBLE	42061
OTTAWA	42062
PAULDING	42063

PERRY	42064
PICKAWAY	42065
PIKE	42066
PORTAGE	42067
PREBLE	42068
PUTNAM	42069
RICHLAND	42070
ROSS	42071
SANDUSKY	42072
SCIOTO	42073
SENECA	42074
SHELBY	42075
STARK	42076
SUMMIT	42077
TRUMBULL	42078
TUSCARAWAS	42079
UNION	42080
VAN WERT	42081
VINTON	42082
WARREN	42083
WASHINGTON	42084
WAYNE	42085
WILLIAMS	42086
WOOD	42087
WYANDOT	42088

OKLAHOMA	16000
ADAIR	16001
ALFALFA	16002
ATOKA	16003
BEAVER	16004
BECKHAM	16005
BLAINE	16006
BRYAN	16007
CADDO	16008
CARTER	16010
CANADIAN	16009
CHEROKEE	16011
CIMARRON	16012
CLEVELAND	16013
COAL	16014
COMANCHE	16015
COTTON	16016
CRAIG	16017
CREEK	16018
CUSTER	16019
DELAWARE	16020
DEWEY	16021
ELLIS	16022
GARFIELD	16023
GARVIN	16024
GRADY	16025
GRANT	16026
GREER	16027
HARMON	16028
HARPER	16029
HASKELL	16030
HUGHES	16031
JACKSON	16032
JEFFERSON	16033
JOHNSTON	16034
KAY	16035
KINGFISHER	16036
KIOWA	16037
LATIMER	16038
LE FLORE	16039
LINCOLN	16040
LOGAN	16041
LOVE	16042
MAJOR	16043
MARSHALL	16044
MAYES	16045
MCCLAIN	16046
MCCURTAIN	16047
MCINTOSH	16048
MURRAY	16049
MUSKOGEE	16050
NOBLE	16051
NOWATA	16052
OKFUSKEE	16053
OKLAHOMA	16054
OKMULGEE	16055
OSAGE	16056
OTTAWA	16057
PAWNEE	16058
PAYNE	16059
PITTSBURG	16060
PONTOTOC	16061
POTTAWATOMIE	16062
PUSHMATAHA	16063
ROGER MILLS	16064
ROGERS	16065
SEQUOYAH	16066
SEMINOLE	16067
STEPHENS	16068
TEXAS	16069
TILLMAN	16070
TULSA	16071
WAGONER	16072
WASHINGTON	16073
WASHITA	16074
WOODS	16075
WOODWARD	16076

OREGON	02000
BAKER	02001
BENTON	02002
CLACKAMAS	02003
CLATSOP	02004
COLUMBIA	02005
COOS	02006
CROOK	02007
CURRY	02008
DESCHUTES	02009
DOUGLAS	02010
GILLIAM	02011
GRANT	02012
HARNEY	02013
HOOD RIVER	02014
JACKSON	02015
JEFFERSON	02016
JOSEPHINE	02017
KLAMATH	02018
LAKE	02019
LANE	02020
LINCOLN	02021

LINN	02022
MALHEUR	02023
MARION	02024
MORROW	02025
MULTNOMAH	02026
POLK	02027
SHERMAN	02028
TILLAMOOK	02029
UMATILLA	02030
UNION	02031
WALLOWA	02032
WASCO	02033
WASHINGTON	02034
WHEELER	02035
YAMHILL	02036

PENNSYLVANIA	43000
ADAMS	43001
ALLEGHANY	43002
ARMSTRONG	43003
BEAVER	43004
BEDFORD	43005
BERKS	43006
BLAIR	43007
BRADFORD	43008
BUCKS	43009
BUTLER	43010
CAMBRIA	43011
CAMERON	43012
CARBON	43013
CENTRE	43014
CHESTER	43015
CLARION	43016
CLEARFIELD	43017
CLINTON	43018
COLUMBIA	43019
CRAWFORD	43020
CUMBERLAND	43021
DAUPHIN	43022
DELAWARE	43023
ELK	43024
ERIE	43025
FAYETTE	43026
FOREST	43027
FRANKLIN	43028
FULTON	43029
GREENE	43030
HUNTINGDON	43031
INOLANA	43032
JEFFERSON	43033
JUNIATA	43034
LACKAWANNA	43035
LANCASTER	43036
LAWRENCE	43037
LEBANON	43038
LEHIGH	43039
LUZERNE	43040
LYCOMING	43041
MCKEAN	43042
MERCER	43043
MIFFLIN	43044
MONROE	43045
MONTGOMERY	43046
MONTOUR	43047
NORTHAMPTON	43048
NORTHUMBERLAND	43049
PERRY	43050
PHILADELPHIA	43051
PIKE	43052
POTTER	43053
SCHUYLKILL	43054
SNYDER	43055
SOMERSET	43056
SULLIVAN	43057
SUSQUEHANNA	43058
TIOGA	43059
UNION	43060
VENANGO	43061
WARREN	43062
WASHINGTON	43063
WAYNE	43064
WESTMORELAND	43065
WYOMING	43066
YORK	43067

PUERTO RICO	51000

RHODE ISLAND	44000
BRISTOL	44001
KENT	44002
NEWPORT	44003
PROVIDENCE	44004
WASHINGTON	44005

SOUTH CAROLINA	45000
ABBEVILLE	45001
AIKEN	45002
ALLENDALE	45003
ANDERSON	45004
BAMBERG	45005
BARNWELL	45006
BEAUFORT	45007
BERKELEY	45008
CALHOUN	45009
CHARLESTON	45010
CHEROKEE	45011
CHESTER	45012
CHESTERFIELD	45013
CLARENDON	45014
COLLETOR	45015
DARLINGTOR	45016
DILLON	45017
DORCHESTER	45018
EDGEFIELD	45019
FAIRFIELD	45020
FLORENCE	45021
GEORGETOWN	45022
GREENVILLE	45023
GREENWOOD	45024
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HORRY	45026
JASPER	45027
KERSHAW	45028

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LEXINGTON	45032
MCCORMICK	45033
MARION	45034
MARLBORO	45035
NEWBERRY	45036
OCONEE	45037
ORANGEBURG	45038
PICKENS	45039
RICHLAND	45040
SALUDA	45041
SPARTENSBURG	45042
SUMTER	45043
UNION	45044
WILLIAMSBURG	45045
YORK	45046

SOUTH DAKOTA	13000
AURORA	13001
BEADLE	13002
BENNETT	13003
BON HOMME	13004
BROOKINGS	13005
BROWN	13006
BRULE	13007
BUFFALO	13008
BUTTE	13009
CAMPBELL	13010
CHARLES MIX	13011
CLARK	13012
CLAY	13013
CODINGTON	13014
CORSON	13015
CUSTER	13016
DAVISON	13017
DAY	13018
DEUEL	13019
DEWEY	13020
DOUGLAS	13021
EDMUNDS	13022
FALL RIVER	13023
FAULK	13024
GRANT	13025
GREGORY	13026
HAAKON	13027
HAMLIN	13028
HAND	13029
HANSON	13030
HARDING	13031
HUGHES	13032
HUTCHINSON	13033
HYDE	13034
JACKSON	13035
JERAULD	13036
JONES	13037
KINGSBURY	13038
LAKE	13039
LAWRENCE	13040
LINCOLN	13041
LYMAN	13042
MARSHALL	13043
MCCOOK	13044
MCPHERSON	13045
MEADE	13046
MELLETTE	13047
MINER	13048
MINNEHAHA	13049
MOODY	13050
PENNINGTON	13051
PERKINS	13052
POTTER	13053
ROBERTS	13054
SANBORN	13055
SHANNON	13056
SPINK	13057
STANLEY	13058
SULLY	13059
TODD	13060
TRIPP	13061
TURNER	13062
UNION	13063
WALWORTH	13064
WASHABAUGH	13065
YANKTON	13066
ZIEBACH	13067

TENNESSEE	46000
ANDERSON	46001
BEDFORD	46002
BENTON	46003
BLEDSOE	46004
BLOUNT	46005
BRADLEY	46006
CAMPBELL	46007
CANNON	46008
CARROLL	46009
CARTER	46010
CHEATHAM	46011
CHESTER	46012
CLAIBORNE	46013
CLAY	46014
COCKE	46015
COFFEE	46016
CROCKETT	46017
CUMBERLAND	46018
DAVIDSON	46019
DECATUR	46020
DE KALB	46021
DICKSON	46022
DYER	46023
FAYETTE	46024
FENTRESS	46025
FRANKLIN	46026
GIBSON	46027
GILES	46028
GRAINGER	46029
GREENE	46030
GRUNDY	46031
HAMBLEN	46032
HAMILTON	46033
HANCOCK	46034
HARDEMAN	46035
HARDIN	46036
HAWKINS	46037
HAYWOOD	46038
HENDERSON	46039

HENRY	46040
HICKMAN	46041
HOUSTON	46042
HUMPHREYS	46043
JACKSON	46044
JEFFERSON	46045
JOHNSON	46046
KNOX	46047
LAKE	46048
LAUDERDALE	46049
LAWRENCE	46050
LEWIS	46051
LINCOLN	46052
LONDON	46053
MCMINN	46054
MCNAIRY	46055
MACON	46056
MADISON	46057
MARION	46058
MARSHALL	46059
MAURY	46060
MEIGS	46061
MONROE	46062
MONTGOMERY	46063
MOORE	46064
MORGAN	46065
OBLON	46066
OVERTON	46067
PERRY	46068
PICKETT	46069
POLK	46070
PUTNAM	46071
RHEA	46072
ROANE	46073
ROBERTSON	46074
RUTHERFORD	46075
SCOTT	46076
SEQUATCHIE	46077
SEVIER	46078
SHELBY	46079
SMITH	46080
STEWART	46081
SULLIVAN	46082
SUMNER	46083
TIPTON	46084
TROUSDALE	46085
UNICOL	46086
UNION	46087
VAN BUREN	46088
WARREN	46089
WASHINGTON	46090
WAYNE	46091
WEAKLY	46092
WHITE	46093
WILLIAMSON	46094
WILSON	46095

TEXAS	17000
ANDERSON	17001
ANDREWS	17002
ANGELINA	17003
ARANSAS	17004
ARCHER	17005
ARMSTRONG	17006
ATASCOSA	17007
AUSTIN	17008
BAILEY	17009
BANDERA	17010
BASTROP	17011
BEE	17012
BELL	17013
BEXAR	17014
BLANCO	17015
BORDEN	17016
BOSQUE	17017
BOWIE	17018
BRAZORIA	17019
BRAZOS	17020
(BREWSTER)	17064
BRISCOE	17021
BROOKS	17022
BROWN	17023
BURLESON	17024
BURNET	17025
CALDWELL	17026
CALHOUN	17027
CALLAHAN	17028
CAMERON	17029
CAMP	17030
CARSON	17031
CASS	17032
CASTRO	17033
CHAMBERS	17034
CHEROKEE	17035
CHILDRESS	17036
CLAY	17037
COCHRAN	17038
COKE	17039
COLEMAN	17040
COLLIN	17041
COLLINGSWORTH	17042
COLORADO	17043
COMAL	17044
COMANCHE	17045
CONCHO	17046
COOKE	17047
CORYELL	17048
COTTLE	17049
CRANE	17050
CROCKETT	17051
CROSBY	17052
CULBERTSON	17053
DALLAM	17054
DALLAS	17055
DAWSON	17056
DAYLOR	17057
DEAF SMITH	17058
DELTA	17059
DENTON	17060
DE WITT	17061
DIMMIT	17062
DONLEY	17063
BREWSTER	17064
DUVAL	17065
EASTLAND	17066
ECTOR	17067
EDWARDS	17068
ELLIS	17069

EL PASO	17070
ERATH	17071
FALLS	17072
FANNIN	17073
FAYETTE	17074
FISHER	17075
FLOYD	17076
FOARD	17077
FORT BEND	17078
FRANKLIN	17079
FREESTONE	17080
FRIO	17081
GAINES	17082
GALVESTON	17083
GARZA	17084
GILLESPIE	17085
GLASS-COCK	17086
GOLIAD	17087
GONZALES	17088
GRAY	17089
GRAYSON	17090
GREGG	17091
GRIMES	17092
GUADALUPE	17093
HALE	17094
HALL	17095
HAMILTON	17096
HANSFORD	17097
HARDEMAN	17098
HARDIN	17099
HARRIS	17100
HARRISON	17101
HARTLEY	17102
HASKELL	17103
HAYS	17104
HEMPHILL	17105
HENDERSON	17106
HIDALGO	17107
HILL	17108
HOCKLEY	17109
HOOD	17110
HOPKINS	17111
HOUSTON	17112
HOWARD	17113
HUDSPETH	17114
HUNT	17115
HUTCHINSON	17116
IRION	17117
JACK	17118
JACKSON	17119
JASPER	17120
JEFF DAVIS	17121
JEFFERSON	17122
JIM HOOG	17123
JOHNSON	17124
JONES	17125
KARNES	17126
KAUFMAN	17127
KENDALL	17128
KENEDY	17129
KENT	17130
KERR	17131
KIMBLE	17132
KING	17133
KINNEY	17134
KLEBERG	17135
KNOX	17136
LAMAR	17137
LAMB	17138
LAMPASAS	17139
LA SALLE	17140
LAVACA	17141
LEE	17142
LEON	17143
LIBERTY	17144
LIMESTONE	17145
LIPSCOMB	17146
LIVE OAK	17147
LLANO	17148
LOVING	17149
LUBBOCK	17150
LYNN	17151
MADISON	17152
MARION	17153
MARTIN	17154
MASON	17155
MATAGORDA	17156
MAVERICK	17157
MCCULLOCH	17158
MCLENNAN	17159
MCMULLEN	17160
MEDINA	17161
MENARD	17162
MIDLAND	17163
MILAM	17164
MILLS	17165
MITCHELL	17166
MONTAGUE	17167
MONTGOMERY	17168
MOORE	17169
MORRIS	17170
MOTLEY	17171
NACOGDOCHES	17172
NAVARRO	17173
NEWTON	17174
NOLAN	17175
NUECES	17176
OCHILTREE	17177
OLDMAN	17178
ORANGE	17179
PALO PINTO	17180
PANOLA	17181
PARKER	17182
PARMER	17183
PECOS	17184
POLK	17185
POTTER	17186
PRESIDIO	17187
RAINS	17188
RANDALL	17189
REAGAN	17190
REAL	17191
RED RIVER	17192
REEVES	17193
REFUGIO	17194
ROBERTS	17195
ROBERTSON	17196
ROCKWALL	17197
RUNNELS	17198
RUSK	17199

SABINE	17200
SAN AUGUSTINE	17201
SAN JACINTO	17202
SAN PATRICIO	17203
SAN SABA	17204
SCHLEICHER	17205
SCURRY	17206
SHACKLEFORD	17207
SHELBY	17208
SHERMAN	17209
SMITH	17210
SOMERVELL	17211
STARR	17212
STEPHENS	17213
STERLING	17214
STONEWALL	17215
SUTTON	17216
SWISHER	17217
TARRANT	17218
TAYLOR	17219
TERRELL	17220
TERRY	17221
THROCKMORTON	17222
TITUS	17223
TOM GREEN	17224
TRAVIS	17225
TRINITY	17226
TYLER	17227
UM WELLS	17228
UPSHUR	17229
UPTON	17230
UVALDE	17231
VAL VERDE	17232
VAN ZANDT	17233
VICTORIA	17234
WALKER	17235
WALLER	17236
WARD	17237
WASHINGTON	17238
WEBB	17239
WHARTON	17240
WHEELER	17241
WITCHITA	17242
WILLACY	17243
WILLIAMSON	17244
WILLSON	17245
WINKLER	17246
WISE	17247
WOOD	17248
YOAKUM	17249
YOUNG	17250
ZAPATA	17251
ZAVALA	17252

UTAH	06000
BEAVER	06001
BOX ELDER	06002
CACHE	06003
CARBON	06004
DAGGETT	06005
DAVIS	06006
DUCHESNE	06007
EMERY	06008
GARFIELD	06009
GRAND	06010
IRON	06011
JUAB	06012
KANE	06013
MILLARD	06014
MORGAN	06015
PIUTE	06016
RICH	06017
SALT LAKE	06018
SAN JUAN	06019
SANPETE	06020
SEVIER	06021
SUMMIT	06022
TOOELE	06023
UINTAH	06024
UTAH	06025
WASATCH	06026
WASHINGTON	06027
WAYNE	06028
WEBER	06029

VERMONT	47000
ADDISON	47001
BENNINGTON	47002
CALEDONIA	47003
CHITTENDON	47004
ESSEX	47005
FRANKLIN	47006
GRAND ISLE	47007
LAMOILLE	47008
ORANGE	47009
ORLEANS	47010
RUTLAND	47011
WASHINGTON	47012
WINDHAM	47013
WINDSOR	47014

VIRGINIA	48000
ACCOMACK	48001
ALBEMARLE	48002
ALLEGHANY	48003
AMELIA	48004
AMHEARST	48005
APPOMATTOX	48006
ARLINGTON	48007
AUGUSTA	48008
BATH	48009
BEDFORD	48010
BLAND	48011
BOTETOURT	48012
BRUNSWICK	48013
BUCHANAN	48014
BUCKINGHAM	48015
CAMPBELL	48016
CAROLINE	48017
CARROLL	48018
CHARLES CITY	48019
CHARLOTTE	48020
CHESTERFIELD	48021
CLARKE	48022
CRAIG	48023
CUIPEPPER	48024

CUMBERLAND	48025
DICKENSON	48026
DINWIDDIE	48027
ESSEX	48028
FAIRFAX	48029
FAUQUIER	48030
FLOYD	48031
FLUVANNA	48032
FRANKLIN	48033
FREDERICK	48034
GILES	48035
GLOUCESTER	48036
GOOCHLAND	48037
GRAYSON	48038
GREENE	48039
GREENSVILLE	48040
HALIFAX	48041
HANOVER	48042
HENRICO	48043
HENRY	48044
HIGHLAND	48045
ISLE OF WIGHT	48046
JAMES CITY	48047
KING AND QUEEN	48048
KING GEORGE	48049
KING WILLIAM	48050
LANCASTER	48051
LEE	48052
LOUDOUN	48053
LOUISA	48054
LURENBURG	48055
MADISON	48056
MATHEWS	48057
MECKLENBURG	48058
MIDDLESEX	48059
MONTGOMERY	48060
NANSEMOND	48061
NELSON	48062
NEW KENT	48063
NORTHAMPTON	48064
NORTHUMBERLAND	48065
NOTTOWAY	48066
ORANGE	48067
PAGE	48068
PATRICK	48069
PITTSYLVANIA	48070
POWHATAN	48071
PRINCE EDWARD	48072
PRINCE GEORGE	48073
PRINCE WILLIAM	48074
PULASKI	48075
RAPPAHANNOCK	48076
RICHMOND	48077
ROANOKE	48078
ROCKBRIDGE	48079
ROCKINGHAM	48080
RUSSELL	48081
SCOTT	48082
SHENANDOAH	48083
SMYTH	48084
SOUTHAMPTON	48085
SPOTSYLVANIA	48086
STAFFORD	48087
SURRY	48088
SUSSEX	48089
TAZEWELL	48090
WARREN	48091
WASHINGTON	48092
WESTMORELAND	48093
WISE	48094
WYTHE	48095
YORK	48096

WASHINGTON	03000
ADAMS	03001
ASUTIN	03002
BENTON	03003
CHELAN	03004
CLALLAM	03005
CLARK	03006
COLUMBIA	03007
COWLITZ	03008
DOUGLAS	03009
FERRY	03010
FRANKLIN	03011
GARFIELD	03012
GRANT	03013
GRAYS HARBOR	03014
ISLAND	03015
JEFFERSON	03016
KING	03017
KLICKITAT	03018
KITSAP	03019
KITTITAS	03020
LEWIS	03021
LINCOLN	03022
MASON	03023
OKANOGAN	03024
PACIFIC	03025
PEND OREILLE	03026
PIERCE	03027
SAN JUAN	03028
SKAGIT	03029
SKAMANIA	03030
SNOHOMISH	03031
SPOKANE	03032
STEVENS	03033
THURSTON	03034
WAHKIAKUM	03035
WALLA WALLA	03036
WHATCOM	03037
WHITMAN	03038
YAKIMA	03039

WEST VIRGINIA	49000
BARBOUR	49001
BERKELEY	49002
BOONE	49003
BRAXTON	49004
BROOKE	49005
CABELL	49006
CALHOUN	49007
CLAY	49008
DODDRIDGE	49009
FAYETTE	49010
GILMER	49011

GRANT	49012
GREENBRIAR	49013
HAMPSHIRE	49014
HANCOCK	49015
HARDY	49016
HARRISON	49017
JACKSON	49018
JEFFERSON	49019
KENAWHA	49020
LEWIS	49021
LINCOLN	49022
LOGAN	49023
MCDOWELL	49024
MARION	49025
MARSHALL	49026
MASON	49027
MERCER	49028
MINERAL	49029
MINGO	49030
MONONGALIA	49031
MONROE	49032
MORGAN	49033
NICHOLAS	49034
OHIO	49035
PENDLETON	49036
PLEASANTS	49037
POCAHONTAS	49038
PRESTON	49039
PUTNAM	49040
RALEIGH	49041
RANDOLPH	49042
RITCHIE	49043
ROANE	49044
SUMMERS	49045
TAYLOR	49046
TUCKER	49047
TYLER	49048
UPSHUR	49049
WAYNE	49050
WEBSTER	49051
WETZEL	49052
WIRT	49053
WOOD	49054
WYOMING	49055
WISCONSIN	50000
ADAMS	50001
ASHLAND	50002
BARRON	50003
BAYFIELD	50004
BROWN	50005
BUFFALO	50006
BURNETT	50007
CALUMET	50008
CHIPPEWA	50009
CLARK	50010
COLUMBIA	50011
CRAWFORD	50012
DANE	50013
DODGE	50014
DOOR	50015
DOUGLAS	50016
DUNA	50017
EAU CLAIRE	50018
FLORENCE	50019
FOND DU LAC	50020
FOREST	50021
GRANT	50022
GREEN	50023
GREEN LAKE	50024
IOWA	50025
IRON	50026
JACKSON	50027
JEFFERSON	50028
JUNEAU	50029
KENOSHA	50030
KEWAUNEE	50031
LA CROSSE	50032
LAFAYETTE	50033
LANGLADE	50034
LINCOLN	50035
MANITOWAC	50036
MARATHON	50037
MARINETTE	50038
MARQUETTE	50039
MENOMONEE	50040
MILWAUKEE	50041
MONROE	50042
OCONTO	50043
ONELDA	50044
OUTAGAMIE	50045
OZAUKEE	50046
PEPIN	50047
PIERCE	50048
POLK	50049
PORTAGE	50050
PRICE	50051
RACINE	50052
RICHLAND	50053
ROCK	50054
RUSK	50055
ST. CROIX	50056
SAUK	50057
SAWYER	50058
SHAWAND	50059
SHEBOYGAN	50060
TAYLOR	50061
TREMPEALEAN	50062
VERNON	50063
VIIAS	50064
WALWORTH	50065
WASHBURN	50066
WASHINGTON	50067
WAUKESHA	50068
WAUPACA	50069
WAUSHARA	50070
WINNEBAGO	50071
WOOD	50072
WYOMING	09000
ALBANY	09001
BIG HORN	09002
CAMPBELL	09003
CARBON	09004
CONVERSE	09005
CROOK	09006

FREMONT	09007
GOSHEN	09008
HOT SPRINGS	09009
JOHNSON	09010
LINCOLN	09011
LARAMIE	09012
NATRONA	09013
NIOBRARA	09014
PARK	09015
PLATTE	09016
SHERIDAN	09017
SUBLETTE	09018
SWEETWATER	09019
TETON	09020
UINTA	09021
WASHAKIE	09022
WESTON	09023
YELLOWSTONE NATIONAL PARK	09024

TREE SPECIES CODES – NUMERIC

000	UNIDENTIFIED GENERA OF SOFTWOODS	(AVOID USE OF 000)
001-499	ALL SOFTWOOD SPECIES	
001	DOUGLAS-FIR	PSEUDOTSUGA MENZIESII
002	DOUGLAS-FIR, BIGCONE	PSEUDOTSUGA MACROCARPA
003		
004		
005	COAST REDWOOD	SEQUOIA SEMPERVIRENS
006	GIANT SEQUOIA	SEQUOIADENDRON GIGANTEA
007	DAWN REDWOOD	METASEQUOIA
008		
009		
010-099	PINE SPP.	
010	PINE, UNIDENTIFIED	PINUS SPP.
011	PINE, PONDEROSA	P. PONDEROSA
012	PINE, JEFFREY	P. JEFFREYI
013	PINE, SUGAR	P. LAMBERTIANA
014	PINE, WESTERN WHITE	P. MONTICOLA
015	PINE, LODGEPOLE	P. CONTORTA
016	PINE, RED	P. RESINOSA
017		
018		
019		
020		
021	PINE, COULTER	P. COULTERI
022	PINE, MONTEREY	P. RADIATA
023	PINE, DIGGER	P. SABINIANA
024	PINE, KNOBCONE	P. ATTENUATA
025	PINE, BISHOP	P. MURICATA
025	PINE, TORREY	P. TORREYANA
025	PINE, WASHOE	P. WASHOENSIS
026	PINE, LIMBER, WHITEBARK	P. SPP.
027	PINE, PINYON, MEXICAN PINYON, PARRY	P. SPP.
027	PINE, PINYON, SINGLELEAF PINYON	P. SPP.
028	PINE, SHORTLEAF	P. ECHINATA
029	PINE, LONGLEAF	P. PALUSTRIS
030	PINE, LOBLOLLY	P. TAEDA
031	PINE, PITCH	P. RIGIDA
032	PINE, EASTERN WHITE	P. STROBUS
033	PINE, VIRGINIA	P. VIRGINIANA
034	PINE, ITALIAN STONE	P. PINEA
035	PINE, ALEPPO	P. HALEPENSIS
036	PINE, JACK	P. BANKSIANA
037	PINE, APACHE, CHIHUAHUA	P. SPP.
038	PINE, SLASH	P. ELLIOTTII
039	PINE, POND	P. SEROTINA
040	PINE, BRISTLECONE, FOXTAIL	P. SPP.
041		
042		
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048		

100-199	FIR SPP.	
100	FIR, UNIDENTIFIED	ABIES SPP.
101	FIR, WHITE	ABIES CONCOLOR
102	FIR, CALIFORNIA RED	ABIES MAGNIFICA
103	FIR, GRAND	ABIES GRANDIS
104	FIR, PACIFIC SILVER	ABIES AMABILIS
105	FIR, NOBLE	ABIES PROCERA
106	FIR, SUBALPINE, CORKBARK	ABIES LASIOCARPA
107	FIR, BRISTLECONE	ABIES BRACTEATA
108	FIR, BALSAM	ABIES BALSAMEA
109		
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200	UNIDENTIFIED GENERA IN CEDAR FAMILY	
201		
202	INCENSE-CEDAR	LIBOCEDRUS DECURRENS
203		
204		
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210		
211	ALASKA-CEDAR	CHAMAECYPARIS NOOTKATENSIS
212	PORT-ORFORD-CEDAR	CHAMAECYPARIS LAWSONIANA
213		
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220	THUJA, UNIDENTIFIED	THUJA SPP.
221	REDCEDAR, WESTERN	THUJA PLICATA
222		
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230	JUNIPER, UNIDENTIFIED	JUNIPERUS SPP.
231	JUNIPER, ALLIGATOR, CALIFORNIA,	JUNIPERUS SPP.
231	JUNIPER, COMMON, ONE-SEED, PINCHOT,	JUNIPERUS SPP.
231	JUNIPER, ROCKY MTN, UTAH, WESTERN	JUNIPERUS SPP.
232	REDCEDAR, EASTERN	JUNIPERUS VIRGINIANA
233		
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270	CYPRESS, UNIDENTIFIED	CUPRESSUS SPP.
271	CYPRESS, ARIZONA, GOWAN, MACNAB,	CUPRESSUS SPP.
271	CYPRESS, MODOC, MONTEREY, TECATE	CUPRESSUS SPP.
272		
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300	SPRUCE, UNIDENTIFIED	PICEA SPP.
301	SPRUCE, ENGELMANN	PICEA ENGELMANNII
302	SPRUCE, SITKA	PICEA SITCHENSIS
303	SPRUCE, BLACK	PICEA MARIANA
304	SPRUCE, WHITE, PARSILD	PICEA GLAUCA
305	SPRUCE, BLUE	PICEA PUNGENS
306	SPRUCE, BREWER	PICEA BREWERIANA
307	SPRUCE, RED	PICEA RUBENS
308		
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350	HEMLOCK, UNIDENTIFIED	TSUGA SPP.
351	HEMLOCK, MOUNTAIN	TSUGA MERTENSIANA
352	HEMLOCK, WESTERN	TSUGA HETEROPHYLLA
353	HEMLOCK, EASTERN	TSUGA CANADENSIS
354	HEMLOCK, CAROLINA	TSUGA CAROLINIANA
355		
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400	LARCH, UNIDENTIFIED	LARIX SPP.
401	LARCH, WESTERN	LARIX OCCIDENTALIS
402	LARCH, SUBALPINE	LARIX LYALLI
403	TAMARACK	LARIX LARICINA
404		
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450	TAXUS, UNIDENTIFIED	TAXUS SPP.
451	YEW, PACIFIC	TAXUS BREVIFOLIA
452	YEW, CANADIAN	TAXUS CANADENSIS
453	YEW, FLORIDA	TAXUS FLORIDANA
454	TORREYA, CALIFORNIA	TORREYA CALIFORNICA
455	TORREYA, FLORIDA	TORREYA TAXIFOLIA
455	STINKING-CEDAR (RARE)	TORREYA TAXIFOLIA
456		
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500-799	HARDWOOD SPECIES EXCLUSIVE OF OAKS	
500	UNIDENTIFIED HARDWOOD SPECIES	(AVOID USE OF 500)
501	ALDER, UNIDENTIFIED	ALNUS SPP.
502	ASH, UNIDENTIFIED	FRAXINUS SPP.
503	ASPEN, QUAKING	POPULUS TREMULOIDES
504	BIRCH, UNIDENTIFIED	BETULA SPP.
505	COTTONWOOD, UNIDENTIFIED	POPULUS SPP.
505	ASPEN, UNIDENTIFIED	POPULUS SPP.
505	POPLAR, UNIDENTIFIED	POPULUS SPP.
506	MAPLE, UNIDENTIFIED	ACER SPP.
507	WILLOW, UNIDENTIFIED	SALIX SPP.
508	BUCKEYE, CALIFORNIA	AESCULUS CALIFORNICA
509	EUCALYPTUS, UNIDENTIFIED	EUCALYPTUS SPP.
510	TANOAK	LITHOCARPUS DENSIFLORA
511	ELM, UNIDENTIFIED	ULMUS SPP.
512	CALIFORNIA-BAY (BELOW 5000 FT)	UMBELLULARIA CALIFORNICA
512	CALIFORNIA-LAUREL (BELOW 5000 FT)	UMBELLULARIA CALIFORNICA
512	OREGON-MYRTLE (BELOW 5000 FT)	UMBELLULARIA CALIFORNICA
512	PEPPERWOOD (BELOW 5000 FT)	UMBELLULARIA CALIFORNICA
513	BUCKTHORN, CALIFORNIA	RHAMNUS CALIFORNICA
514	CHINKAPIN, GOLDEN	CASTANOPSIS CHRYSOPHYLLA
515	MADRONE, UNIDENTIFIED	ARBUTUS SPP.
516	DOGWOOD, UNIDENTIFIED	CORNUS SPP.
517	SYCAMORE, UNIDENTIFIED	PLATANUS SPP.
518	LOCUST, UNIDENTIFIED	ROBINIA SPP.
519	WALNUT, BLACK	JUGLANS NIGRA
520	ACACIA, BROADLEAF	ACACIA LATIFOLIA
521	ACACIA, UNIDENTIFIED	ACACIA SPP.
522	BEECH, UNIDENTIFIED	FAGUS SPP.
523	TAMARISK, UNIDENTIFIED	TAMARIX SPP.
524	HACKBERRY, UNIDENTIFIED	CELTIS SPP.
525	HICKORY, UNIDENTIFIED	CARYA SPP.
526	ELDER, UNIDENTIFIED (NOT BOXELDER)	SAMBUCUS SPP.
526	ELDERBERRY, UNIDENTIFIED	SAMBUCUS SPP.
527	MYRICA SPP., UNIDENTIFIED	MYRICA SPP.
527	WAXMYRTLE, PACIFIC	MYRICA SPP.
527	SWEETBAY, SIERRA	MYRICA SPP.
527	BAYBERRY, PACIFIC	MYRICA SPP.
528	LAUREL, AMERICAN (7000-12000 FT)	KALMIA LATIFOLIA
528	MOUNTAIN-LAUREL (7000-12000 FT)	KALMIA LATIFOLIA
529	PEPPERTREE, CALIFORNIA	SCHINUS MOLLE
530	TREE OF HEAVEN	AILANTHUS ALTISSIMA
530	AILANTHUS	AILANTHUS ALTISSIMA
531	FIG, UNIDENTIFIED	FICUS SPP.
532	PISTACHE, TEXAS	PISTACIA TEXANA
533	GOLDENCHAIN TREE	LABURNUM WATERERI

534	TUPELO, UNIDENTIFIED	NYSSA SPP.
535	IRON TREE	METROSIDEROS TOMENTOSA
535	NEW ZEALAND CHRISTMAS TREE	METROSIDEROS TOMENTOSA
536	MESQUITE, UNIDENTIFIED	PROSOPIS SPP.
537	SUMAC, UNIDENTIFIED	RHUS SPP.
538	MULBERRY, UNIDENTIFIED	MORUS SPP.
539	REDGUM	LIQUIDAMBAR STYRACIFLUA
539	SWEETGUM	LIQUIDAMBAR STYRACIFLUA
540	HOLLY, UNIDENTIFIED	ILEX SPP.
541	BASSWOOD, UNIDENTIFIED	TILIA SPP.
541	LINDEN, UNIDENTIFIED	TILIA SPP.
542	CATALPA, UNIDENTIFIED	CATALPA SPP.
543	PERSIMMON, COMMON	DIOSPYROS VIRGINIANA
544	CASCARA	RHAMNUS PURSHIANA
544	BUCKTHORN, CASCARA	RHAMNUS PURSHIANA
545	COFFEETREE, KENTUCKY	GYMNOCLADUS DIOICUS
546	REDBUD, UNIDENTIFIED	CERCIS SPP.
547	APPLE, UNIDENTIFIED	MALUS SPP.
548	CHERRY, UNIDENTIFIED	PRUNUS SPP.
549	CAROB	CERATONIA SILIQUA
550	PECAN	CARYA ILLINOENSIS
551	HAWTHORN, UNIDENTIFIED	CRATAEGUS SPP.
552	CHINABERRY	MELIA AZEDARACH
552	UMBRELLA-TREE	MELIA AZEDARACH
553	OSAGE-ORANGE	MACLURA POMIFERA
554	YELLOW-POPLAR	LIRIODENDRON TULIPIFERA
554	TULIPTREE	LIRIODENDRON TULIPIFERA
555	HERCULES-CLUB TREE	ZANTHOXYLUM CLAVA-HERCULIS
556	COTTONWOOD, FREMONT	POPULUS FREMONTII
557	RUSSIAN-OLIVE	ELAEAGNUS ANGUSTIFOLIA
558	PEACH	PRUNUS PERSICA
559	SANDALWOOD, BASTARD	MYOPORUM SANDWICENSE
560	CALIFORNIA-LILAC	CEANOTHUS THYRSIFLORUS
560	BLUEBLOSSOM	CEANOTHUS THYRSIFLORUS
561	TOYON	PHOTINIA ARBUTIFOLIA
561	HOLLYBERRY	PHOTINIA ARBUTIFOLIA
561	CHRISTMASBERRY	PHOTINIA ARBUTIFOLIA
562	OLEANDER, COMMON	NERIUM OLEANDER
563	SOURWOOD	OXYDENDRUM ARBOREUM
564	WALNUT, ARIZONA	JUGLANS MAJOR
565	MAGNOLIA, UNIDENTIFIED	MAGNOLIA SPP.
566	LAURELCHERRY, MYRTLE	PRUNUS MYRTIFOLIA
567	LAUREL, GRECIAN	LAURUS NOBILIS
567	BAY, SWEET (NOT SWEETBAY)	LAURUS NOBILIS
568	CHESTNUT, UNIDENTIFIED	CASTANEA SPP.
569	LOCUST, BLACK	ROBINIA PSEUDOACACIA
570	SILK-OAK	GREVILLEA ROBUSTA
571	ALDER, WHITE	ALNUS RHOMBIFOLIA
572	ALDER, RED	ALNUS RUBRA
573	HORNBEAM, AMERICAN (BLUE BEECH)	CARPINUS CAROLINIANA
574	MESQUITE, COMMON	PROSOPIS JULIFLORA
575	WILLOW, BLACK	SALIX NIGRA
576		
577		
578		
579		
580	ASPEN, BIGTOOTH	POPULUS GRANDIDENTATA
581	COTTONWOOD, BLACK	POPULUS TRICHOCARPA
582	COTTONWOOD, EASTERN	POPULUS DELTOIDES
583	COTTONWOOD, SWAMP	POPULUS HETEROPHYLLA
584	POPLAR, BALSAM	POPULUS BALSAMIFERA
585		
586		
587		
588		
589		

590	WALNUT, UNIDENTIFIED	JUGLANS SPP.
591	BUTTERNUT	JUGLANS CINEREA
592	WALNUT, CALIFORNIA	JUGLANS CALIFORNICA
593	WALNUT, HINDS	JUGLANS HINDSII
594		
595		
596	HICKORY, BITTERNUT	CARYA CORDIFORMIS
597	HICKORY, BLACK	CARYA TEXANA
598	HICKORY, MOCKERNUT	CARYA TOMENTOSA
599	HICKORY, PIGNUT	CARYA GLABRA
600	HICKORY, SHAGBARK	CARYA OVATA
601	HICKORY, SHELLBARK	CARYA LACINIOSA
602		
603		
604		
605		
606	BIRCH, GRAY	BETULA POPULIFOLIA
607	BIRCH, PAPER	BETULA PAPYRIFERA
608	BIRCH, RIVER	BETULA NIGRA
609	BIRCH, SWEET	BETULA LENTA
610	BIRCH, WATER	BETULA OCCIDENTALIS
611	BIRCH, YELLOW	BETULA ALLEGHANIENSIS
612		
613		
614		
615	ATHEL	TAMARIX ARTICULATA
616	ALDER, EUROPEAN	ALNUS GLUTINOSA
617	ALDER, THINLEAF	ALNUS TENNIFOLIA
618		
619		
620		
621		
622		
623		
624		
625	HOPHORNBEAM, UNIDENTIFIED	OSTRYA SPP.
626	HOPHORNBEAM, EASTERN	OSTRYA VIRGINIANA
627	HOPHORNBEAM, KNOWLTON (WESTERN)	OSTRYA KNOWLTONII
628		
629		
630	HAZEL, UNIDENTIFIED	CORYLUS SPP.
631	HAZEL, AMERICAN	CORYLUS AMERICANA
632	HAZEL, BEAKED	CORYLUS ROSTRATA
633	HAZEL, CALIFORNIA	CORYLUS CORNUTA
634	HAZEL, GIANT	CORYLUS MAXIMA
635		
636	BEECH, AMERICAN	FAGUS GRANDIFOLIA
637	BEECH, EUROPEAN	FAGUS SYLVATICA
638		
639		
640	CHESTNUT, AMERICAN	CASTANEA DENTATA
641	CHESTNUT, CHINESE	CASTANEA MOLLISIMA
642	CHESTNUT, JAPANESE	CASTANEA CRENATA
643	CHESTNUT, SPANISH	CASTANEA SATIVA
644		
645		
646		
647		
648		
649		
650	CHINKAPIN, UNIDENTIFIED	CASTANOPSIS SPP.
651	CHINKAPIN, ALLEGHENY	CASTANOPSIS PUMILA
652		
653		
654		

655	ELM, AMERICAN	ULMUS AMERICANA
656	ELM, CEDAR	ULMUS CRASSIFOLIA
657	ELM, RED	ULMUS SEROTINA
658	ELM, ROCK	ULMUS THOMASII
659	ELM, SLIPPERY	ULMUS RUBRA
660	ELM, WINGED	ULMUS ALATA
661	ELM, CHINESE	ULMUS PARVIFOLIA
662		
663		
664		
665	HACKBERRY	CELTIS OCCIDENTALIS
666	SUGARBERRY (HACKBERRY)	CELTIS LAEVIGATA
667		
668		
669		
670		
671	MULBERRY, BLACK	MORUS NIGRA
672	MULBERRY, RED	MORUS RUBRA
673	MULBERRY, TEXAS	MORUS MICROPHYLLA
674	MULBERRY, WHITE	MORUS ALBA
675		
676	FIG, COMMON	FICUS CARICA
677	FIG, FLORIDA STRANGLER	FICUS AUREA
678	FIG, SHORTLEAF	FICUS LAEVIGATE
679		
680	CUCUMBERTREE	MAGNOLIA ACUMINATA
681	MAGNOLIA, BIGLEAF	MAGNOLIA MACROPHYLLA
682	MAGNOLIA, FRASER	MAGNOLIA FRASERI
683	MAGNOLIA, SOUTHERN	MAGNOLIA GRANDIFLORA
684	MAGNOLIA, UMBRELLA	MAGNOLIA TRIPETALA
685	MAGNOLIA, SWEETBAY	MAGNOLIA VIRGINIANA
686		
687		
688		
689		
690	SASSAFRASS	SASSAFRASS ALBIDUM
691		
692	REDBAY	PERSEA BORBONIA
693		
694	WITCH-HAZEL	HAMAMELIS VIRGINIANA
695	SYCAMORE, ARIZONA	PLATANUS WRIGHTII
696	SYCAMORE, AMERICAN	PLATANUS OCCIDENTALIS
697	SYCAMORE, CALIFORNIA	PLATANUS RACEMOSA
698		
699		
700	APPLE, COMMON	MALUS PUMILA
701	APPLE, SOUTHERN CRAB	MALUS ANGUSTIFOLIA
702	APPLE, SWEET CRAB	MALUS CORONARIA
703		
704		
705	CHERRY, BLACK	PRUNUS SEROTINA
706	CHERRY, HOLLYLEAF	PRUNUS ILICIFOLIA
707		
708	CHERRY, PIN	PRUNUS PENSYLVANICA
709	CHOKECHERRY, COMMON	PRUNUS VIRGINIANA
710		
711		
712		
713		
714		
715		
716		
717	PEAR, COMMON	PYRUS COMMUNIS
718		
719		
720	HAWTHORN, BLACK	CRATAEGUS DOUGLASII

721	HAWTHORN, COCKSPUR	CRATAEGUS CRUS-GALLI
722		
723		
724		
725		
726		
727		
728		
729		
730	ACACIA, CATCLAW	ACACIA GREGGII
731	ACACIA, SWEET	ACACIA FARNESIANA
732		
733		
734		
735		
736	REDBUD, CALIFORNIA	CERCIS OCCIDENTALIS
737	REDBUD, EASTERN	CERCIS CANADENSIS
737	JUDAS-TREE	CERCIS CANADENSIS
738	HONEYLOCUST, UNIDENTIFIED	GLEDITSIA SPP.
739	HONEYLOCUST	GLEDITSIA TRIACANTHOS
740	HONEYLOCUST, TEXAS	GLEDITSIA TEXANA
741	WATERLOCUST	GLEDITSIA AQUATICA
742		
743	SUMAC, STAGHORN	RHUS TYPHINA
744	POISON-SUMAC	TOXICODENDRON VERNIX
745	HOLLY, AMERICAN	ILEX OPACA
746	HOLLY, CAROLINA	ILEX AMBIGUA
747	HOLLY, GEORGIA	ILEX LONGIPES
748	WINTERBERRY, MOUNTAIN	ILEX MONTANA
749		
750	BOXELDER	ACER NEGUNDO
751	MAPLE, BIGLEAF	ACER MACROPHYLLUM
752	MAPLE, BLACK	ACER NIGRUM
753	MAPLE, RED	ACER RUBRUM
754	MAPLE, ROCKY MOUNTAIN	ACER GLABRUM
755	MAPLE, SILVER	ACER SACCHARINUM
756	MAPLE, STRIPED	ACER PENSYLVANICUM
757	MAPLE, SUGAR	ACER SACCHARUM
758		
759		
760	BUCKEYE, OHIO	AESCULUS GLABRA
761	BUCKEYE, YELLOW	AESCULUS OCTANDRA
762	HORSECHESTNUT	AESCULUS HIPPOCASTANUM
763		
764	CEANOTHUS, SPINY	CEANOTHUS SPINOSUS
765	BASSWOOD, AMERICAN	TILIA AMERICANA
766	BASSWOOD, WHITE	TILIA HETEROPHYLLA
767	DOGWOOD, RED-OSIER	CORNUS STOLONIFERA
768	DOGWOOD, FLOWERING	CORNUS FLORIDA
769	DOGWOOD, PACIFIC	CORNUS NUTTALLII
770	TUPELO, BLACK	NYSSA SYLVATICA
771	TUPELO, WATER	NYSSA AQUATICA
772	MADRONE, PACIFIC	ARBUTUS MENZIESII
773	ASH, BLACK	FRAXINUS NIGRA
774	ASH, BLUE	FRAXINUS QUADRANGULATA
775	ASH, CAROLINA	FRAXINUS CAROLINIANA
776	ASH, GREEN	FRAXINUS PENNSYLVANICA
777	ASH, OREGON	FRAXINUS LATIFOLIA
778	ASH, WHITE	FRAXINUS AMERICANA
779		
780	CATALPA, NORTHERN	CATALPA SPECIOSA
781	CATALPA, SOUTHERN	CATALPA BIGNONIOIDES
782		
783	TAMARISK, FIVE-STAMEN	TAMARIX PENTANDRA
784	TAMARISK, SMALLFLOWER	TAMARIX PARVIFLORA
785		

786	ELDER, AMERICAN	SAMBUCUS CANADENSIS
787	ELDER, MEXICAN	SAMBUCUS MEXICANA
787	ELDERBERRY, DESERT	SAMBUCUS MEXICANA
788	ELDER, PACIFIC RED	SAMBUCUS CALLICARPA
789	ELDERBERRY, BLUE	SAMBUCUS GLAUCA
790	SOAPBERRY, UNIDENTIFIED	SAPINDUS SPP.
791		
792	MANZANITA, EASTWOOD	ARCTOSTAPHYLOS GLANDULOSA
793		
794	LAUREL, UNIDENTIFIED (PUERTO RICO)	LAURACEAE
795		
796	PALO COLORADO	CYRILLA RACEMIFLORA
797		
798		
799		

NOTE L = LIVE, W = WHITE, R-B = RED OR BLACK

800-899	OAKS			
800	OAK, UNIDENTIFIED	QUERCUS SPP.		
801	CALIF. BLACK	Q. KELLOGGII	ORE.,CALIF.	(R-B)
802	LIVE,CALIF.	Q. AGRIFOLIA	CALIF.	(R-B:L)
802	LIVE,COAST	Q. AGRIFOLIA	CALIF.	(R-B:L)
803	CALIF. WHITE	Q. LOBATA	CALIF.	(W)
803	VALLEY	Q. LOBATA	CALIF.	(W)
804	LIVE,CANYON	Q. CHRYSOLEPIS	CALIF.,ORE.,NEV.	(W:L)
804	LIVE,WHITE	Q. CHRYSOLEPIS	CALIF.,ORE.,NEV.	(W:L)
804	MAUL	Q. CHRYSOLEPIS	TEX, OKLA.	(W:L)
805	LIVE,HIGHLAND	Q. WISLIZENII	CALIF.	(R-B:L)
805	LIVE,INTERIOR	Q. WISLIZENII	CALIF.	(R-B:L)
805	LIVE,SIERRA	Q. WISLIZENII	CALIF.	(R-B:L)
806	GARRY	Q. GARRYANA	WASH.,ORE.,CALIF.	(W)
806	OREGON WHITE	Q. GARRYANA	WASH,ORE,CALIF.	(W)
807	GAMBEL	Q. GAMBELII	NW, SW	(W)
807	WHITE,ROCKY MTN	Q. GAMBELII	NW, SW	(W)
808	SOUTHERN RED	Q. FALCATA V FALCATA	NE, SE	(R-B)
809	POST	Q. STELLATA	NE, SE	(W)
810	BLACK	Q. MARILANDICA	NE, SE	(R-B)
810	BLACKJACK	Q. MARILANDICA	NE, SE	(R-B)
811	RED	Q. NIGRA	NE, SE	(R-B)
811	WATER	Q. NIGRA	NE, SE	(R-B)
812	CHERRYBARK	Q. FALCATA V PAGODAEFOLIA	NE, SE	(R-B)
812	RED	Q. FALCATA V PAGODAEFOLIA	NE, SE	(R-B)
813	MOHRS	Q. MOHRIANA	TEX.,OKLA.	(W)
813	SCRUB	Q. MOHRIANA	TEX.,OKLA.	(W)
813	SHIN OAK	Q. MOHRIANA	TEX,OKLA.	(W)
814	LIVE (SE)	Q. VIRGINIANA	SE	(W:L)
814	LIVE,SCRUB	Q. VIRGINIANA	SE	(W:L)
815	BLUE	Q. DOUGLASII	CALIF.	(W)
815	MOUNTAIN WHITE	Q. DOUGLASII	CALIF.	(W)
816	RED	Q. PHELLOS	NE, SE	(R-B)
816	WILLOW	Q. PHELLOS	NE, SE	(R-B)
817	CALIF. SCRUB	Q. DUMOSA	CALIF.	(W:L)
817	LIVE,CAL.SCRUB	Q. DUMOSA	CALIF.	(W:L)
818	BUR	Q. MACROCARPA	NE, SE	(W)
819	DURAND	Q. DURANDII	SE	(W)
820	LIVE, UNIDENTIFIED - FROM CALIFORNIA OR FAR WEST			

821	BLACK	Q. COCCINEA	NE, SE	(R-B)
821	RED	Q. COCCINEA	NE, SE	(R-B)
821	SCARLET	Q. COCCINEA	NE, SE	(R-B)
822	WHITE	Q. ALBA	NE, SE	(W)
823	NORTHERN RED	Q. RUBRA	NE, SE	(R-B)
824	BLACK, UNIDENT.	Q. SPP.		(R-B)
824	RED, UNIDENT.	Q. SPP.		(R-B)
825	BLACK	Q. VELUTINA	NE, SE	(R-B)
826	WHITE, UNIDENT.	Q. SPP.		(W)
827	BLUEJACK	Q. INCANA	SE	
827	SANDJACK	Q. INCANA	SE	
828	CHESTNUT	Q. MICHAUXII	SE, TEXAS	
829	EMORY	Q. EMORYI	SW	(R-B)
830				
831				
832				
833				
834				
835				
836				
837				

900-948	CODE NUMBERS FOR ADDITIONAL SPECIES.	
949	SAHUARO	CEREUS GIGANTEUS
950	PALM, UNIDENTIFIED	PALMAE
951-998	CODE NUMBERS FOR ADDITIONAL SPECIES.	
999	GENUS UNKNOWN	(AVOID USE OF 999)

MASTER FORM

REPORT OF TREE FAILURE ①
(Mechanical break, collapse, or uprooting)

1/1/1-5 1 2 1 5 Number: ______

1 1 6 1 2 6 Card: 1
2

REPORTING AGENCY: ______

UNIT: ______ 1 44 51

(A) Tree and stand

1 7 9 Species: ______
1 11 12 Approximate dbh of tree: ______ inches
1 14 16 Approximate age of tree: ______ years
1 18 19 Forest type: ______
1 21 Stand age class: ___ Overmature
___ Mature
___ Young-growth
___ All-age
1 23-25 Elevation of site: ______ ______

1/27 (B) Class of mechanical failure

- ___ Upper bole (top half)
- ___ Lower bole
- ___ Butt (lower 6 feet)
- ___ Limb
- ___ Root, including uprooting

1/29-30 (C) Tree defect or fault leading to failure ②

- 1 32 33 ___ Rot (trunk, limb, or root)
- 1 35-36 ___ Sweep
- ___ Tree dead - snag
- ___ Fire wound
- ___ Leaning
- ___ Lightning wound
- ___ Mechanical wound
- ___ Cracks or splits
- ___ Fork or multiple top
- ___ Twin bole or basal fork
- ___ Dead top or branch
- ___ Widow-maker or hang-up
- ___ Canker, rust
- ___ Canker, mistletoe
- ___ Other: ______
- ___ Unknown or none

1 38 (D) Contributing factors

- 1 40 ___ Wind
- 1 42 ___ Snow
- ___ Erosion
- ___ Soil - saturation
- ___ Stream bank erosion
- ___ Shallow rooting
- ___ Tree striking tree
- ___ Other: ______
- ___ Unknown or none

(E) Time and location of incident 1/52

Approximate hour: ______ 1/53-54
Month, year: ______ 1/56-59
County: ______ 1 63 65
State: ______ 1 61 62
Site open for public use: Yes ___ No ______ 1 67

(F) Land ownership 1/69

- ___ Federal
- ___ State
- ___ Other public: ______
- ___ Private
- ___ Public utility

(G) Site category 1/71

- ___ Established camp or picnic ground
- ___ Other established public use site ③
- ___ Volunteer site ④
- ___ Marked trail
- ___ Special use site ⑤
- ___ Roadside
- ___ Residence site ⑥
- ___ Other: ⑦ ______
- ___ Urban

(H) Property or person directly affected 1 73

- ___ Agency
- ___ Recreationist
- ___ Forest industry
- ___ Permittee-Concessionaire
- ___ Other: ______
- ___ Contractor
- ___ Public utility

(I) Consequences

- ___ Clean-up work required 1 2 80
- ___ Property damaged: ______ 1/75, 2/7 2/9-13
- Property loss estimate: $______ 2 14 18
  (Do not give tree values)
- ___ Injuries 1 77 2 20
- ___ Medical attention required 2 22
- ___ Fatalities 1 79 2 24

. . . . 2 26
. . . . 2 27 31
. . . . 2 33 38
. . . . 2 40 42

2 44 78 (J) Name of site: ⑧ ______

Comments: ______
______
______

Only failures of a size capable of inflicting some damage or injury should be reported. Minor limb failures should not be reported unless they were potentially dangerous. Do not report simple death of a tree or part of a tree unless it resulted in mechanical failure. Trees removed prior to failure should not be reported.

Forest Service Form PSW-4600-3 (Rev 6/75)

① A report should be made for:

- (1) each tree failure involving property damage or bodily injury;
- (2) each failure adjacent to permanent recreation facilities, home sites, or other locations where failures are a threat to property, and;
- (3) each failure on recreation sites and other high use locations during the season of public use, whether or not the failure causes damage or injury.

② Check only those defects and contributing factors which lead to the actual failure.

③ Other established public use site: Winter sports, beaches, viewpoints, visitor centers, historical buildings, etc.

④ Volunteer site: Undeveloped site with concentrated public use.

⑤ Special use site: Resorts, service facilities, etc.

⑥ Residence site: Agency, private, or permittee-lessor.

⑦ Other: Wilderness area sites, open forest, etc.

⑧ Published analyses will not indicate the source of specific incidents.

If many failures occur in your area, reports may be limited to managed sites normally subject to inspection and hazard control. Where information is available, however, reports from volunteer and other noninspected sites will be of value.

NOTE: A SEPARATE FORM SHOULD BE COMPLETED FOR EACH INDIVIDUAL FAILURE. Inclusion of more than one failure on a report prevents correlation of data unless all details are identical.

Additional forms may be obtained from your headquarters or by writing to the following address:

Return to: Lee A. Paine
U.S.D.A. Forest Service
P.O. Box 245
Berkeley, California 94701

Commercial Phone: (415) 486-3158
FTS Phone: 449-3158

MASTER FORM

1/1-5 2 1 5 Number: ___________

REPORT OF TREE FAILURE ①

(Mechanical break, collapse, or uprooting)

1 6 2 6 Card: 1
2

REPORTING AGENCY: ______________________ UNIT: ______________________ 1 44 51

(A) Tree and stand

1 7 9 Species: ______________________

1 11 12 Approximate dbh of tree: ____________ inches

1 14 16 Approximate age of tree: ____________ years

1 18 19 Forest type: ______________________

1 21 Stand age class: ___ Overmature
___ Mature
___ Young-growth
___ All-age

1 23 25 Elevation of site: ______________________

1 27 **(B) Class of mechanical failure**

___ Upper bole (top half)
___ Lower bole
___ Butt (lower 6 feet)
___ Limb
___ Root, including uprooting

1 29-30 **(C) Tree defect or fault leading to failure** ②

1/32-33 ___ Rot (trunk, limb, or root)
1 35-36 ___ Sweep
___ Tree dead - snag
___ Fire wound
___ Leaning
___ Lightning wound
___ Mechanical wound
___ Cracks or splits
___ Fork or multiple top
___ Twin bole or basal fork
___ Dead top or branch
___ Widow-maker or hang-up
___ Canker, rust
___ Canker, mistletoe
___ Other: ______________________
___ Unknown or none

1 38 **(D) Contributing factors**

1 40 ___ Wind
1 42 ___ Snow
___ Erosion
___ Soil - saturation
___ Stream bank erosion
___ Shallow rooting
___ Tree striking tree
___ Other: ____________
___ Unknown or none

2 44-78 **(J)** Name of site: ⑧ ______________________

Comments: ______________________

____

____

(E) Time and location of incident 1/52

Approximate hour: ______________________ 1/53-54

Month, year: ______________________ 1/56-59

County: ______________________ 1 63 65

State: ______________________ 1/61-62

Site open for public use: Yes ____ No ________ 1/67

(F) Land ownership 1/69

___ Federal
___ State
___ Other public: ______________________
___ Private
___ Public utility

(G) Site category 1/71

___ Established camp or picnic ground
___ Other established public use site ③
___ Volunteer site ④
___ Marked trail
___ Special use site ⑤
___ Roadside
___ Residence site ⑥
___ Other: ⑦ ______________________
___ Urban

(H) Property or person directly affected 1/73

___ Agency
___ Recreationist
___ Forest industry
___ Permittee-Concessionaire
___ Other: ______________________
___ Contractor
___ Public utility

(I) Consequences

___ Clean-up work required 1/2/80
___ Property damaged: ________________ 1/75, 2/7, 2/9-13
Property loss estimate: $________________ 2/14-18
___ Injuries (Do not give tree values) 1 77 2 20
___ Medical attention required 2/22
___ Fatalities 1 79 2 24

..............2 26
.... 2 27 31
..............2 33 38
..............2 40 42

Only failures of a size capable of inflicting some damage or injury should be reported. Minor limb failures should not be reported unless they were potentially dangerous. Do not report simple death of a tree or part of a tree unless it resulted in mechanical failure. Trees removed prior to failure should not be reported.

Forest Service Form PSW-4600-3 (Rev 6/75)

① A report should be made for:

(1) each tree failure involving property damage or bodily injury;

(2) each failure adjacent to permanent recreation facilities, home sites, or other locations where failures are a threat to property, and;

(3) each failure on recreation sites and other high use locations during the season of public use, whether or not the failure causes damage or injury.

② Check only those defects and contributing factors which lead to the actual failure.

③ Other established public use site: Winter sports, beaches, viewpoints, visitor centers, historical buildings, etc.

④ Volunteer site: Undeveloped site with concentrated public use.

⑤ Special use site: Resorts, service facilities, etc.

⑥ Residence site: Agency, private, or permittee-lessor.

⑦ Other: Wilderness area sites, open forest, etc.

⑧ Published analyses will not indicate the source of specific incidents.

If many failures occur in your area, reports may be limited to managed sites normally subject to inspection and hazard control. Where information is available, however, reports from volunteer and other noninspected sites will be of value.

NOTE: A SEPARATE FORM SHOULD BE COMPLETED FOR EACH INDIVIDUAL FAILURE. Inclusion of more than one failure on a report prevents correlation of data unless all details are identical.

Additional forms may be obtained from your headquarters or by writing to the following address:

Return to: Lee A. Paine
U.S.D.A. Forest Service
P.O. Box 245
Berkeley, California 94701

Commercial Phone: (415) 486-3158
FTS Phone: 449-3158

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The Pacific Southwest Forest and Range Experiment Station

represents the research branch of the Forest Service in California and Hawaii.

MARGIN INDEX

To use the margin index, bend the book in half and follow the index to the page with the edge marker.

- Guidelines for Coding
- Codes for Failure Report—Outline
- Target Value Guide
- Tree Species Codes—Alphabetic
- Forest Type Codes and Descriptions
- Agency Codes—Outline
- Agency Codes—Detail
  - Forest Service
  - State Agencies
- State and County Codes
- Tree Species Codes—Numeric

MYSTIC MOUNTAIN:

an educational alternative futures wildland planning game

Edward C. Thor James L. Creighton

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USDA FOREST SERVICE
GENERAL TECHNICAL
REPORT PSW-30

The Authors

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ACKNOWLEDGMENT

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1978. **Mystic Mountain: an educational alternative futures wildland planning game.** Gen. Tech. Rep. PSW-30, 8 p., illus. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

Alternative futures planning is a generic name for a number of planning approaches which recognize that the future is uncertain. There is not one future, preordained and universally known, but rather a variety of possible futures, any one of which may occur. *Mystic Mountain* is an educational game which teaches wildland planners and managers important concepts in alternative futures planning while they attempt to manage a hypothetical national forest for 75 years. It combines education and fun in a few hours of playing time.

Retrieval Terms: Forest management; resource management; futures planning; alternatives management games.

MYSTIC MOUNTAIN:
an educational alternative futures wildland planning game

Edward C. Thor James L. Creighton

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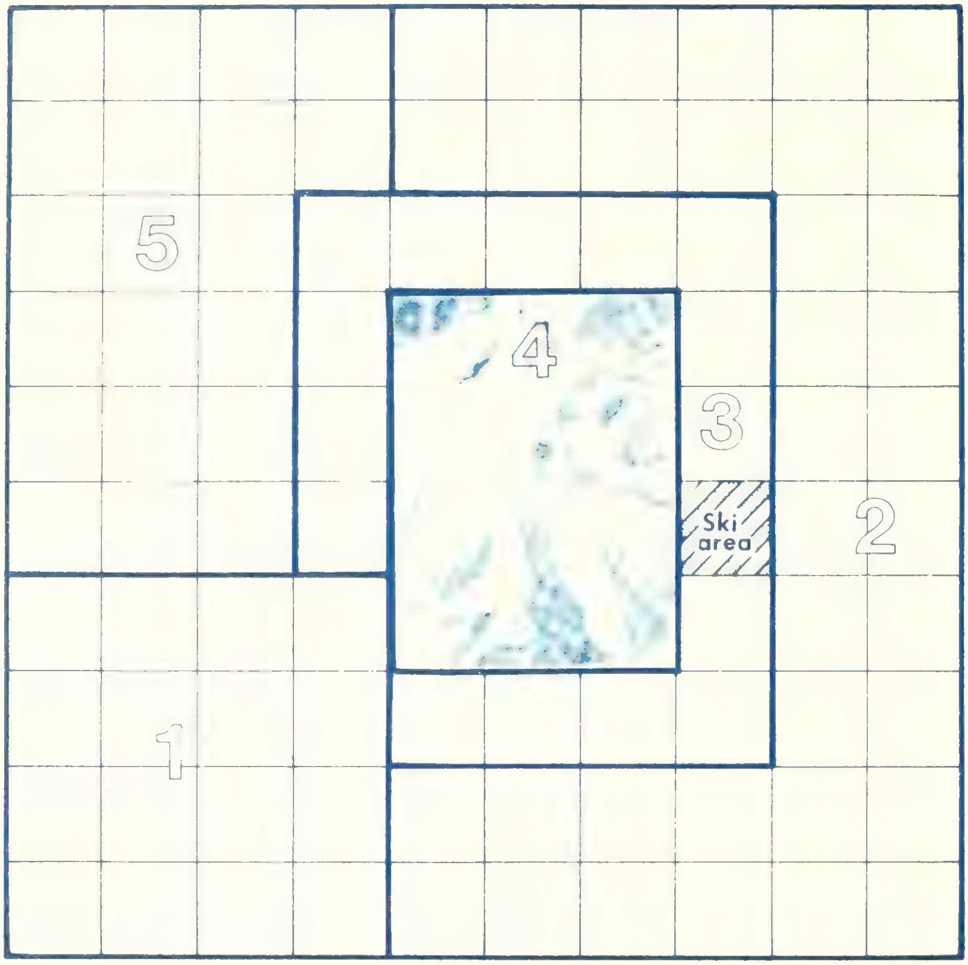
Pacific Southwest Forest and Range Experiment Station
P.O. Box 245
Berkeley, California 94701

December 1978

MYSTIC MOUNTAIN
NATIONAL FOREST



Team ______________________ Period ______________________

COLOR CODE

yellow	☐	Camping
red	☐	Primitive recreation
blue	☐	Skiing
green	☐	Timber harvesting
brown	☐	– Spiritual value
	▨	· Existing use To indicate old or existing uses at beginning of period, use diagonal lines of appropriate color.
	☐	New use To indicate uses added during period, use solid color.

OUTPUT

	Required	Produced
1.		
2.		
3.		
4.		
5.		

Note: Each square = 1000 acres.

"This game is serious!" "No, this game is fun!" These comments by players are both right. Mystic Mountain is an educational tool, a game, which teaches wildland planners and managers important concepts of alternative futures planning. The game is patterned after the management of a hypothetical mountainous national forest. During the play of the game, in which 75 years are condensed into approximately 4 hours, the players work together in small teams to manage an area of land, attempting to meet the demands imposed on them by a changing world. The land being managed has potential for a wide variety of uses, from preservation to intensive summer recreation, ski area development, and timber harvesting.[1] The game is designed so that every team can win, but only if they apply several basic concepts of alternative futures planning.

Games can be valuable educational tools, especially for communicating concepts. If they are enjoyable, games capture interest and involve the student in learning in a way that a lecture or a book cannot. The challenge and competition are an immediate motivation for learning, reinforcing the long-term motivation supplied by the knowledge that the concepts to be learned may be useful in the future. People are more receptive to ideas which they associate with pleasurable experiences. Through involvement in a game players can discover concepts for themselves, and thus acquire a deeper understanding and acceptance than can be achieved in a lecture. A realistic game, especially one with which the players personally identify, gives substance to abstract concepts. It lets the players taste in just a few hours the rewards of learning and applying these concepts, as well as the consequences of failing to apply them. In the real world these rewards and consequences may take decades to unfold. To condense these decades into a few hours, however, requires that the planning situation be simplified. The players, who may recognize these simplifications for what they are, accept the necessary rules and restrictions as part of the game and do not demand a precise simulation of the real world.

The game described here introduces alternative futures planning—a generic name for a number of planning approaches[2] which recognize that the future is uncertain, and that there is not one future, preordained and universally known, but rather a variety of possible futures, any of which may occur. To some degree, we can control the future by working toward the future that we desire. However, to a large degree the future is beyond our control and we discover it as it occurs. Many planning processes ignore this, and prepare to respond only to the most probable future or to the planning organization's "official" future. Alternative futures planning, on the other hand, explicitly recognizes the variety of possible futures, strives to identify decisions that destroy future options, and dictates management which meets the demands of today while preserving or enhancing ability to meet the demands of a number of possible tomorrows.

The Mystic Mountain game teaches several important concepts from alternative futures planning, concepts that could be adapted to a wide variety of planning processes.

1. There are alternative futures, which place different demands on land managers. In the Mystic Mountain game, a set of believable scenarios—short word pictures of the future--describe alternative conditions under which the players may have to manage the land. A different set of demands has been developed for each scenario. Because the players do not know which of the futures will occur, yet must be prepared to meet the demands of any future, the players are forced into planning for a range of alternative futures.

2. The preservation of options is important. The goal of the players is to manage the land, meeting the demands of the scenarios that occur. Because it is impossible to meet all the demands of all the scenarios simultaneously, the players soon discover that

(a) The management activities they choose foreclose future options and their ability to meet the demands of the scenarios.

(b) Some activities in some locations foreclose more options than others.

(c) A careful choice of activities will preserve enough options to meet the demands.

(d) It is sometimes important to delay a decision about the use of a prime site, because the demands of the different possible futures would dictate different uses.

---

[1] Another version of the game, in which coal development becomes a key issue, is available. Although it differs in details, it is played in the same way and teaches the same concepts. Using the version which most closely reflects the players' involvement in planning often increases learning.

[2] For one such approach see Creighton, James L., 1976, *Alternative Futures Planning*, Div. of Planning Coordination, Bur. Reclam., U.S. Dep. of Inter., Denver, Colo. 141 p.

3. Some activities actually create future options. Through proper sequencing, the same piece of land can provide many seemingly conflicting outputs over time. For example, no one wants to camp in the middle of a recently logged, slash-filled area, yet that same area can be the site of a beautiful campground 30 years after logging. Therefore the game requires a delay between seriously conflicting uses of the same land. Players who put off decisions too long find themselves unable to schedule a second use of a site. Where conflicting uses must be spread out over time, the failure to act may eliminate the choice of providing both uses.

4. Meeting the demands faced by wildland management organizations requires careful, long-range planning. At the beginning of a game the players find themselves responsible for meeting these demands for a period of 75 years. They must meet the demands of today, but they also must be prepared to meet the demands of tomorrow. By following the same piece of land through 75 years, they experience at first-hand the rewards of careful planning and the punishments of inadequate planning.

Although the game is complete by itself, it is most educational when used as part of a one day workshop or training session. A suitable training session format includes a presentation of the concept of alternative futures and scenarios, and a discussion of the types of scenarios that may influence future wildland management. The discussion is followed by the game, which teaches planning and management concepts, and then by a discussion of the game. This format leaves a couple of hours in the afternoon for additional training or discussion of related subjects.

PLAYING THE GAME

The instructor or workshop leader should act as the game leader. After introducing the game, the leader divides the players into teams of two or three people.

Each team is given a copy of the game description, five copies of the Mystic Mountain map, and colored pencils for filling in the maps. Any number of teams can play at one time, but if there are more than five teams the leader should probably have help. One assistant for every five additional teams is needed to answer questions, assure that the rules are being followed, check the maps, and lead group discussions.

The game is conducted during five periods, each one representing 15 years of elapsed time. The first period should last one hour, and all subsequent periods 30 minutes.

At the beginning of each time period, the leader reads the current situation description for that period (see p. 8). This tells the players what has occurred in the world during the last 15 years, what scenario they can expect for the next 15 years, and thus what are the minimum output levels they must provide. The current situation description provided has been chosen to emphasize the teaching points discussed earlier, but alternative current situation descriptions could be easily prepared.

Next, each team examines the productivity information and rules included in the game description. The team members decide where to build campgrounds, harvest trees, preserve in a natural state, and so on, during that time period, in order to meet the demands of the current situation. The locations chosen are entered on a copy of the Mystic Mountain map, using the appropriate color codes.

For all periods except the last, once the decisions are recorded, someone in the team should copy the information onto another copy of the map as existing uses, to be used during the next period. The earlier map is then given to the leader to be checked. For consistency, when coloring the maps, all teams should use the same color codes (as shown on map, or as decided by the leader), should indicate old or existing uses at the beginning of a period with appropriately colored diagonal lines on the map for that period, and should use solid colors for uses added during that period. The leader should check the completed maps for errors during the next time period, and then return them to the teams. Any errors should be immediately reported to the team for correction before that team prepares its map for the next period.

After all five time periods have been played, one member of each team is asked to present an account of what the team did and why they were or were not able to win. The leader should steer the discussion to the teaching points presented earlier, if these do not arise naturally, and should encourage the players to discuss how their strategies and game experiences related to these points. This is also an ideal time to discuss the implications of the game for the players' roles in wildland planning and management.

The following section describes the game. A copy of these pages is given to every team. Duplicate pages for copying are provided following page 8.

MYSTIC MOUNTAIN: AN ALTERNATIVE FUTURES PLANNING GAME

This game is designed to simulate the management of the Mystic Mountain National Forest for a period of 75 years. You are a member of the management team.

The Mystic Mountain National Forest consists of Mystic Mountain peak itself, and the surrounding land. Mystic Mountain is world renowned for the beauty of its snowcapped peak. The mountain rises abruptly out of the surrounding valley floor, and is unquestionably the dominant geographic feature of the area for about 100 miles around.

The problem of managing the Mystic Mountain National Forest is uncertainty about what it should be managed *for*. A number of competing uses of the land are possible, and it is presently very difficult to predict which demands upon the land will be of greatest importance in future years.

Competing Uses of the Land

1. *Timber Harvesting*—There is a considerable amount of prime timberland within the forest. All timber is harvested by clear-cutting, the most suitable method for the species present.

2. *Primitive Recreation Activities*—Because the Mystic Mountain area is quite famous, there is strong demand for dispersed recreation activities (such as hiking, backcountry camping, and fishing) in a primitive setting. The demand for this type of recreation has grown dramatically during the last 10 years, and may continue to do so.

3. *Camping*—There is also a great demand for campgrounds, often by persons using campers and trailers. Mystic Mountain is just a few miles off the main north-south highway in the State, so there has been a steady increase in demand for developed camping sites.

4. *Skiing*—A small ski area currently exists on Mystic Mountain. This area can be expanded to provide additional skier capacity. The major question is whether or not the demand for skiing in this area will continue to grow. This ski area has to compete with major regional ski areas closer to the metropolitan area which are currently more developed. There is a certain amount of condominium and second-home development related to skiing, on private land which adjoins the forest.

5. *Spiritual Values*—Portions of Mystic Mountain are considered to be sacred by local Indian tribes. In addition, several unorthodox religious groups believe that Mystic Mountain has special spiritual significance, and there are now several religious retreats on private land in the area.

Physical Characteristics

The Forest is divided into five main areas, each of which has different use characteristics.

Area 1

16,000 acres. Relatively modest potential for camping, primitive recreation activities and timber. No skiing. No spiritual value.

Area 2

36,000 acres. Relatively good camping and primitive recreation potential. Moderate timber potential. No skiing. No spiritual value.

Area 3

16,000 acres. This is the area of greatest conflict. It has excellent timber and summer recreational potential. It is the site of all ski development. It also has spiritual value.

Area 4

12,000 acres. This is the peak of the mountain and can be used only for primitive recreation and to provide spiritual value.

Area 5

20,000 acres. This area has relatively good camping, primitive recreation, and timber potential. There is no skiing or spiritual value.

Quantitative descriptions of the productivity of each of these units are given in *table 1.*

Alternative Future Scenarios

A team of Forest personnel, researchers, and consultants have identified a set of four scenarios—short word pictures of the future—which portray the most likely conditions under which the land will be managed over the next 75 years. These scenarios are summarized below.

1. *A Gas Shortage*—A major fuel shortage severely restricts use of the private automobile. Fuel is available for public transportation on a priority basis. At

Mystic Mountain, restrictions on use of private automobiles would greatly reduce the amount of summer recreation (both primitive and developed camping) and skiing. Since Mystic Mountain is a few miles from the railroad, possibly weekend and summer rail transportation could be arranged for recreationists, but certainly recreation use would not continue to grow at its present rate. With recreation use significantly reduced, the land could be managed for timber, but the repercussions of the energy shortage on building would reduce the need for intensive timber management. The effects of a fuel shortage are estimated to last for approximately 15 years, at which time it is assumed other energy sources will have been developed.

2. *Continued Growth in Mass Recreation*—The current trends of expansion in demand for recreation opportunities are assumed to continue. In particular there are demands for large increases in skiing and camp sites, with some increased demand for primitive recreation activities. There is considerable development of second homes and condominiums on adjoining land. Recreation and tourism become more important than timber in the local economy.

3. *Primitive Recreation Activities and Spiritual Values*—A major values shift has occurred, so that Americans are now placing greater emphasis on environmental values, with a down-playing of material values. The result is a great increase in demand for primitive recreation activities, and a modest increase in camping and skiing. A part of the values shift is a change in religious beliefs, with mystic and Eastern religions assuming greater importance. Many religious groups consider Mystic Mountain to be sacred, and fight for preservation of its spiritual values. Spiritual experiences are now considered an essential part of adulthood for a number of these groups, and individuals often spend a week in such places as Mystic Mountain on a spiritual quest. However, as there has been no decline in population, demand for timber from the mountain at a level equal to the present rate of production continues.

4. *A Timber Shortage*—A major timber shortage is assumed, with an increased 15-year demand of 90 million board feet over the present from the Mystic Mountain National Forest. This increase in timber production is in response to political pressure from lower and middle socio-economic groups who are not able to afford a home. In addition, because most nonrenewable resources are very scarce, a number of processes have been developed for use of wood fiber for various products instead of nonrenewable materials such as petroleum. Since these major increases in timber production must be accomplished by clearcutting on this National Forest, the land becomes less attractive for dispersed recreation activities. There is a continuing demand for camp sites, however. Because of the unique character of Mystic Mountain, the demand that the peak (which has almost no timber value) be preserved for spiritual values continues.

NOTE: Any of the scenarios may occur initially. The likelihood of a major fuel shortage occurring decreases sharply after the first 30 years. Because the future is uncertain, it is highly desirable to manage the land in such a way that options are preserved, so that in the future the land can be managed in response to any of the scenarios.

Minimum output requirements for each scenario are shown for each 15-year period in *table 2.* Requirements vary according to scenario, by period.

Table 1 *Productivity of areas of Forest, according to use*

Area (acres)	Camping	Primitive recreation activities	Skiing	Timber	Spiritual value
	Visitor days 1000 acres year			*Million bd.ft./ 1000 acres*	
1. 16,000	2000	1000	–	5	Low
2. 36,000	4000	2000	–	10	Low
3. 16,000	8000	3000	20,000	40	High
4. 12,000	–	500	–		High
5. 20,000	4000	2000	–	20	Low

Table 2 *Minimum output requirements by scenario and time period of plan*

Scenario and period	Camping	Primitive recreation activities	Skiing	Timber harvest	Spiritual value
	Thousand visitor days year			*Million bd ft. (total for period)*	*Acres of high value*[1]
All:					
Period 1	10	20	20	180	15,000
1. Gas shortage:					
Period 2	8	15	16	120	15,000
Period 3	18	16	17	120	15,000
Period 4	10	18	18	120	15,000
Period 5	11	20	20	120	15,000
2. Continued growth in mass recreation:					
Period 2	22	25	40	180	15,000
Period 3	34	30	60	180	15,000
Period 4	46	35	80	180	15,000
Period 5	58	40	100	180	15,000
3. Primitive recreation activities, spiritual values:					
Period 2	18	27	25	180	22,000
Period 3	26	33	30	180	22,000
Period 4	34	41	35	180	22,000
Period 5	42	49	40	180	22,000
4. Timber shortage:					
Period 2	16	22	25	270	15,000
Period 3	22	24	30	270	15,000
Period 4	28	20	35	270	15,000
Period 5	34	15	40	270	15,000

[1] 2 acres of medium spiritual value equal 1 acre of high value.

Rules

Object—The object of the game is to manage the Mystic Mountain National Forest for a total of 75 years, meeting the minimum output requirements for each 15-year period, regardless of which scenario occurs. The game is played against these standards, so that none, a few, or all of the teams could win.

Materials—Each team is given five maps of the Forest, productivity information for the Forest, a table of minimum outputs required for each period under several possible future scenarios, and colored pencils to mark the location of management activities on the map.

Play—There are five time periods of play each representing 15 years. At the beginning of each time period, the leader of the game will indicate what scenario and minimum output levels are in force for the next 15 years. Each team then examines the options and indicates the location of management activities needed to meet the output requirements. If the team cannot meet all of the output targets, it should attempt to identify what previous actions or situations prevented it from reaching the targets for later discussion. Even if a team is unable to meet all the targets in one time period, it should continue to play the game in future time periods, taking advantage of options that open up over time and hoping for a change in scenarios.

NOTE: The minimum output levels for each separate scenario can be reached, *although some require a careful sequencing of activities. The ability to respond to changing scenarios during the play of the game depends on a combination of foresight and luck. Teams which take the time to develop long-range management plans should have an advantage.*

At the end of each time period the game leader collects the maps containing that period's activities and checks them for errors. Thus, toward the end of each period except the last, someone on each team must prepare the map to be used during the next period by copying all existing uses—including those begun in this period—onto a fresh copy of the map. The first time period will be 1 hour long, and the others will last 30 minutes.

Restrictions—In an effort to reflect reality and keep the problem simple enough to be solved in a limited time, certain basic rules for each kind of management activity have been formulated.

Campgrounds

1. No campground can be built on a site that has been logged in the immediately preceding time period.
2. To justify the initial expense, once a campground is built it must be operated as a campground for two periods before it can be used for another purpose.

Primitive Recreation Activities

1. Land which has been managed for primitive recreation activities can be diverted to other uses at any time.
2. No land may be used for primitive recreation activities if it has been previously logged at any time during the game.
3. A campground must have been closed and left idle for one time period before that land becomes suitable for primitive recreation activities.

Ski Area Construction

1. The only ski area sites on Mystic Mountain are in area 3.
2. All expansion must be contiguous to the existing site and occur in 1000-acre blocks.
3. Ski area construction can follow any other activity. Logging and ski area development can occur in consecutive periods, but not in the same period, as time must be allowed to assure trees of sufficient height along the ski runs.
4. Ski area construction is permanent. No other management activity can occur on this land during the game once it has been developed for skiing.

Timber Harvesting

1. All logging is by clearcutting.
2. The rotation age is 75 years; each acre in the forest can be cut only once during the game.

Spiritual Values

1. Only areas 3 and 4 have high spiritual value.
2. Land which has previously been logged can provide only low spiritual value.
3. Land previously a campground must have been left idle for at least one time period before it provides high spiritual value.
4. Primitive recreation lands can provide spiritual value, but if an area of high spiritual value is also used for primitive recreation, it is reduced to a medium level of spiritual value.
5. In meeting the demands for spiritual value, two acres having medium spiritual value are equivalent to one acre having high spiritual value.

The effects of one use on the ability of the land to sustain other uses are summarized in *table 3.*

Table 3—*Use restrictions during the game*

Use	Effect on other uses of the same land during later periods of the game				
	Camping	Primitive recreation activities	Skiing	Timber harvest	Spiritual value
Camping	–	Wait 3 periods, last one with land idle.	Wait 2 periods	Wait 2 periods	Wait 3 periods, last one with land idle.
Primitive recreation activities	No effect	–	No effect	No effect	Reduces high value to medium if at the same time.
Skiing	Option foreclosed	Option foreclosed	–	Option foreclosed	Option foreclosed
Timber harvest	Wait 2 periods	Option foreclosed	Wait 1 period	–	Option foreclosed
Spiritual value	No effect	No effect	No effect	No effect	–

Current Situation Instructions

Leader—At the beginning of each time period during the play of the game, read the current situation for that period. For your use in checking the completed maps after each period, a summary of required minimum outputs is given in *table 4*.

Period 1

You are the managers of the Mystic Mountain National Forest. The only existing facility at this time is a small ski area in unit 3 as shown on your map. You may place all other activities and facilities anywhere you wish on the Forest, consistent with the rules. For minimum output levels you must provide, refer to *table 2*. In 1 hour I will collect the maps you have prepared showing the location of activities and facilities. At that time I will tell you which of the scenarios is occurring and, therefore, what your required minimum output levels for the next period will be. Don't forget to copy the locations from your period 1 map onto your period 2 map as existing facilities before you give me your first map.

Period 2

Fifteen years have now passed. The mass recreation trends of 15 years ago continued, with their resulting high-level mass recreation demands on Mystic Mountain. For the next 15 years you should provide the minimum output levels listed in *table 2* under the mass recreation scenario, Period 2. You have one half hour to prepare your maps for this and all future time periods.

Period 3

You are now 30 years into managing the Mystic Mountain National Forest. The feared gas shortage never did occur, and the danger is now past. For the next 15 years the mass recreation scenario will continue. At the same time, the conditions of the primitive recreation and spiritual value scenario have occurred recently. Thus, for the next 15 years you must manage the Mystic Mountain National Forest in order to meet the demands of both scenarios 2 and 3. That is, for each output you should compare the minimum requirements for the third period in each scenario and produce whichever amount is higher. You have 30 minutes to complete your maps.

NOTE: At this point we have played a small trick on the players by giving them the demands of two scenarios to satisfy when they were only warned to expect one. This should help the players realize that the scenarios need not be mutually exclusive in real life, and that even the uncertainties are uncertain.

Period 4

During the last 15 years there has been a significant shift in the living conditions in the U.S., so that the timber shortage scenario, 4, is now in effect. For the next time period you should meet the minimum output levels given under Scenario 4, Period 4.

Period 5

The timber shortage continues. Finish the game by meeting the required output levels for period 5 of this scenario.

NOTE: New "current situation instructions" can be developed by varying the scenarios chosen in periods 2 through 5 when a number of the players are playing the game for the second time. To do this, choose a sequence of scenarios other than those contained in these instructions and prepare a short explanation for each time period of why one scenario is replaced by another. The players continue to use tables 1, 2, and 3 to determine productivity levels and minimum outputs.

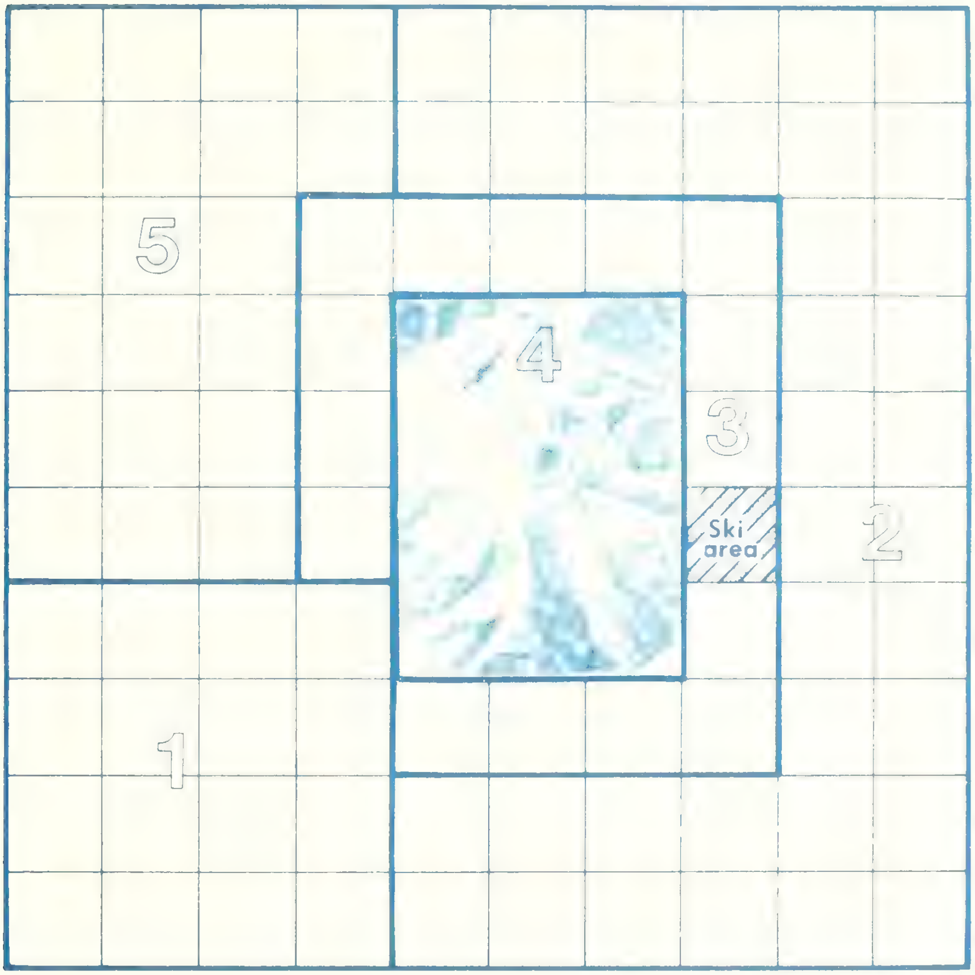
Table 4—*Current situation minimum output requirements*

Period	Scenario	Camping	Primitive recreation activities	Skiing	Timber harvest	Spiritual value
		Thousand visitor days/year			*Million bd. ft. (total for period)*	*Acres of high value*[1]
1	All	10	20	20	180	15,000
2	2	22	25	40	180	15,000
3	2 or 3	34	33	60	180	22,000
4	4	28	20	35	270	15,000
5	4	34	15	40	270	15,000

[1] 2 acres of medium spiritual value equal 1 acre of high value.

MYSTIC MOUNTAIN

NATIONAL FOREST



Team ____________________ Period ____________________

COLOR CODE

yellow ☐ – Camping

red ☐ – Primitive recreation

blue ☐ – Skiing

green ☐ – Timber harvesting

brown ☐ – Spiritual value

▨ Existing use
To indicate old or existing uses at beginning of period, use diagonal lines of appropriate color.

☐ – New use
To indicate uses added during period, use solid color.

OUTPUT

	Required	Produced
1.	______	______
2.	______	______
3.	______	______
4.	______	______
5.	______	______

Note: Each square = 1000 acres.

MYSTIC MOUNTAIN: AN ALTERNATIVE FUTURES PLANNING GAME

This game is designed to simulate the management of the Mystic Mountain National Forest for a period of 75 years. You are a member of the management team.

The Mystic Mountain National Forest consists of Mystic Mountain peak itself, and the surrounding land. Mystic Mountain is world renowned for the beauty of its snowcapped peak. The mountain rises abruptly out of the surrounding valley floor, and is unquestionably the dominant geographic feature of the area for about 100 miles around.

The problem of managing the Mystic Mountain National Forest is uncertainty about what it should be managed *for.* A number of competing uses of the land are possible, and it is presently very difficult to predict which demands upon the land will be of greatest importance in future years.

Competing Uses of the Land

1. *Timber Harvesting*—There is a considerable amount of prime timberland within the forest. All timber is harvested by clear-cutting, the most suitable method for the species present.

2. *Primitive Recreation Activities*—Because the Mystic Mountain area is quite famous, there is strong demand for dispersed recreation activities (such as hiking, backcountry camping, and fishing) in a primitive setting. The demand for this type of recreation has grown dramatically during the last 10 years, and may continue to do so.

3. *Camping*—There is also a great demand for campgrounds, often by persons using campers and trailers. Mystic Mountain is just a few miles off the main north-south highway in the State, so there has been a steady increase in demand for developed camping sites.

4. *Skiing*—A small ski area currently exists on Mystic Mountain. This area can be expanded to provide additional skier capacity. The major question is whether or not the demand for skiing in this area will continue to grow. This ski area has to compete with major regional ski areas closer to the metropolitan area which are currently more developed. There is a certain amount of condominium and second-home development related to skiing, on private land which adjoins the forest.

5. *Spiritual Values*—Portions of Mystic Mountain are considered to be sacred by local Indian tribes. In addition, several unorthodox religious groups believe that Mystic Mountain has special spiritual significance, and there are now several religious retreats on private land in the area.

Physical Characteristics

The Forest is divided into five main areas, each of which has different use characteristics.

Area 1

16,000 acres. Relatively modest potential for camping, primitive recreation activities and timber. No skiing. No spiritual value.

Area 2

36,000 acres. Relatively good camping and primitive recreation potential. Moderate timber potential. No skiing. No spiritual value.

Area 3

16,000 acres. This is the area of greatest conflict. It has excellent timber and summer recreational potential. It is the site of all ski development. It also has spiritual value.

Area 4

12,000 acres. This is the peak of the mountain and can be used only for primitive recreation and to provide spiritual value.

Area 5

20,000 acres. This area has relatively good camping, primitive recreation, and timber potential. There is no skiing or spiritual value.

Quantitative descriptions of the productivity of each of these units are given in *table 1.*

Alternative Future Scenarios

A team of Forest personnel, researchers, and consultants have identified a set of four scenarios—short word pictures of the future—which portray the most likely conditions under which the land will be managed over the next 75 years. These scenarios are summarized below.

1. *A Gas Shortage*—A major fuel shortage severely restricts use of the private automobile. Fuel is available for public transportation on a priority basis. At

Mystic Mountain, restrictions on use of private automobiles would greatly reduce the amount of summer recreation (both primitive and developed camping) and skiing. Since Mystic Mountain is a few miles from the railroad, possibly weekend and summer rail transportation could be arranged for recreationists, but certainly recreation use would not continue to grow at its present rate. With recreation use significantly reduced, the land could be managed for timber, but the repercussions of the energy shortage on building would reduce the need for intensive timber management. The effects of a fuel shortage are estimated to last for approximately 15 years, at which time it is assumed other energy sources will have been developed.

2. *Continued Growth in Mass Recreation*—The current trends of expansion in demand for recreation opportunities are assumed to continue. In particular there are demands for large increases in skiing and camp sites, with some increased demand for primitive recreation activities. There is considerable development of second homes and condominiums on adjoining land. Recreation and tourism become more important than timber in the local economy.

3. *Primitive Recreation Activities and Spiritual Values*—A major values shift has occurred, so that Americans are now placing greater emphasis on environmental values, with a down-playing of material values. The result is a great increase in demand for primitive recreation activities, and a modest increase in camping and skiing. A part of the values shift is a change in religious beliefs, with mystic and Eastern religions assuming greater importance. Many religious groups consider Mystic Mountain to be sacred, and fight for preservation of its spiritual values. Spiritual experiences are now considered an essential part of adulthood for a number of these groups, and individuals often spend a week in such places as Mystic Mountain on a spiritual quest. However, as there has been no decline in population, demand for timber from the mountain at a level equal to the present rate of production continues.

4. *A Timber Shortage*—A major timber shortage is assumed, with an increased 15-year demand of 90 million board feet over the present from the Mystic Mountain National Forest. This increase in timber production is in response to political pressure from lower and middle socio-economic groups who are not able to afford a home. In addition, because most nonrenewable resources are very scarce, a number of processes have been developed for use of wood fiber for various products instead of nonrenewable materials such as petroleum. Since these major increases in timber production must be accomplished by clearcutting on this National Forest, the land becomes less attractive for dispersed recreation activities. There is a continuing demand for camp sites, however. Because of the unique character of Mystic Mountain, the demand that the peak (which has almost no timber value) be preserved for spiritual values continues.

NOTE: Any of the scenarios may occur initially. The likelihood of a major fuel shortage occurring decreases sharply after the first 30 years. Because the future is uncertain, it is highly desirable to manage the land in such a way that options are preserved, so that in the future the land can be managed in response to any of the scenarios.

Minimum output requirements for each scenario are shown for each 15-year period in *table 2.* Requirements vary according to scenario, by period.

Table 1–*Productivity of areas of Forest, according to use*

Area (acres)	Camping	Primitive recreation activities	Skiing	Timber	Spiritual value
	Visitor days/1000 acres/year			*Million bd.ft./1000 acres*	
1. 16,000	2000	1000		5	Low
2. 36,000	4000	2000		10	Low
3. 16,000	8000	3000	20,000	40	High
4. 12,000		500			High
5. 20,000	4000	2000		20	Low

Table 2- *Minimum output requirements by scenario and time period of play*

Scenario and period	Camping	Primitive recreation activities	Skiing	Timber harvest	Spiritual value
	Thousand visitor days/year			*Million bd. ft. (total for period)*	*Acres of high value*[1]
All:					
Period 1	10	20	20	180	15,000
1. Gas shortage					
Period 2	8	15	16	120	15,000
Period 3	18	16	17	120	15,000
Period 4	10	18	18	120	15,000
Period 5	11	20	20	120	15,000
2. Continued growth in mass recreation:					
Period 2	22	25	40	180	15,000
Period 3	34	30	60	180	15,000
Period 4	46	35	80	180	15,000
Period 5	58	40	100	180	15,000
3. Primitive recreation activities, spiritual values:					
Period 2	18	27	25	180	22,000
Period 3	26	33	30	180	22,000
Period 4	34	41	35	180	22,000
Period 5	42	49	40	180	22,000
4. Timber shortage:					
Period 2	16	22	25	270	15,000
Period 3	22	24	30	270	15,000
Period 4	28	20	35	270	15,000
Period 5	34	15	40	270	15,000

[1] 2 acres of medium spiritual value equal 1 acre of high value.

Rules

Object—The object of the game is to manage the Mystic Mountain National Forest for a total of 75 years, meeting the minimum output requirements for each 15-year period, regardless of which scenario occurs. The game is played against these standards, so that none, a few, or all of the teams could win.

Materials—Each team is given five maps of the Forest, productivity information for the Forest, a table of minimum outputs required for each period under several possible future scenarios, and colored pencils to mark the location of management activities on the map.

Play—There are five time periods of play each representing 15 years. At the beginning of each time period, the leader of the game will indicate what scenario and minimum output levels are in force for the next 15 years. Each team then examines the options and indicates the location of management activities needed to meet the output requirements. If the team cannot meet all of the output targets, it should attempt to identify what previous actions or situations prevented it from reaching the targets for later discussion. Even if a team is unable to meet all the targets in one time period, it should continue to play the game in future time periods, taking advantage of options that open up over time and hoping for a change in scenarios.

NOTE: The minimum output levels for each separate scenario can be reached, *although some require a careful sequencing of activities. The ability to respond to changing scenarios during the play of the game depends on a combination of foresight and luck. Teams which take the time to develop long-range management plans should have an advantage.*

At the end of each time period the game leader collects the maps containing that period's activities and checks them for errors. Thus, toward the end of each period except the last, someone on each team must prepare the map to be used during the next period by copying all existing uses—including those begun in this period—onto a fresh copy of the map. The first time period will be 1 hour long, and the others will last 30 minutes.

Restrictions—In an effort to reflect reality and keep the problem simple enough to be solved in a limited time, certain basic rules for each kind of management activity have been formulated.

Campgrounds

1. No campground can be built on a site that has been logged in the immediately preceding time period.
2. To justify the initial expense, once a campground is built it must be operated as a campground for two periods before it can be used for another purpose.

Primitive Recreation Activities

1. Land which has been managed for primitive recreation activities can be diverted to other uses at any time.
2. No land may be used for primitive recreation activities if it has been previously logged at any time during the game.
3. A campground must have been closed and left idle for one time period before that land becomes suitable for primitive recreation activities.

Ski Area Construction

1. The only ski area sites on Mystic Mountain are in area 3.
2. All expansion must be contiguous to the existing site and occur in 1000-acre blocks.
3. Ski area construction can follow any other activity. Logging and ski area development can occur in consecutive periods, but not in the same period, as time must be allowed to assure trees of sufficient height along the ski runs.
4. Ski area construction is permanent. No other management activity can occur on this land during the game once it has been developed for skiing.

Timber Harvesting

1. All logging is by clearcutting.
2. The rotation age is 75 years; each acre in the forest can be cut only once during the game.

Spiritual Values

1. Only areas 3 and 4 have high spiritual value.
2. Land which has previously been logged can provide only low spiritual value.
3. Land previously a campground must have been left idle for at least one time period before it provides high spiritual value.
4. Primitive recreation lands can provide spiritual value, but if an area of high spiritual value is also used for primitive recreation, it is reduced to a medium level of spiritual value.
5. In meeting the demands for spiritual value, two acres having medium spiritual value are equivalent to one acre having high spiritual value.

The effects of one use on the ability of the land to sustain other uses are summarized in *table 3.*

Table 3 – *Use restrictions during the game*

Use	Effect on other uses of the same land during later periods of the game				
	Camping	Primitive recreation activities	Skiing	Timber harvest	Spiritual value
Camping		Wait 3 periods, last one with land idle.	Wait 2 periods	Wait 2 periods	Wait 3 periods, last one with land idle.
Primitive recreation activities	No effect		No effect	No effect	Reduces high value to medium if at the same time.
Skiing	Option foreclosed	Option foreclosed		Option foreclosed	Option foreclosed
Timber harvest	Wait 2 periods	Option foreclosed	Wait 1 period		Option foreclosed
Spiritual value	No effect	No effect	No effect	No effect	

FOR LEADER ONLY

Current Situation Instructions

Leader At the beginning of each time period during the play of the game, read the current situation for that period. For your use in checking the completed maps after each period, a summary of required minimum outputs is given in *table 4*.

Period 1

You are the managers of the Mystic Mountain National Forest. The only existing facility at this time is a small ski area in unit 3 as shown on your map. You may place all other activities and facilities anywhere you wish on the Forest, consistent with the rules. For minimum output levels you must provide, refer to *table 2*. In 1 hour I will collect the maps you have prepared showing the location of activities and facilities. At that time I will tell you which of the scenarios is occurring and, therefore, what your required minimum output levels for the next period will be. Don't forget to copy the locations from your period 1 map onto your period 2 map as existing facilities before you give me your first map.

Period 2

Fifteen years have now passed. The mass recreation trends of 15 years ago continued, with their resulting high-level mass recreation demands on Mystic Mountain. For the next 15 years you should provide the minimum output levels listed in *table 2* under the mass recreation scenario, Period 2. You have one half hour to prepare your maps for this and all future time periods.

Period 3

You are now 30 years into managing the Mystic Mountain National Forest. The feared gas shortage never did occur, and the danger is now past. For the next 15 years the mass recreation scenario will continue. At the same time, the conditions of the primitive recreation and spiritual value scenario have occurred recently. Thus, for the next 15 years you must manage the Mystic Mountain National Forest in order to meet the demands of both scenarios 2 and 3. That is, for each output you should compare the minimum requirements for the third period in each scenario and produce whichever amount is higher. You have 30 minutes to complete your maps.

NOTE: At this point we have played a small trick on the players by giving them the demands of two scenarios to satisfy when they were only warned to expect one. This should help the players realize that the scenarios need not be mutually exclusive in real life, and that even the uncertainties are uncertain.

Period 4

During the last 15 years there has been a significant shift in the living conditions in the U.S., so that the timber shortage scenario, 4, is now in effect. For the next time period you should meet the minimum output levels given under Scenario 4, Period 4.

Period 5

The timber shortage continues. Finish the game by meeting the required output levels for period 5 of this scenario.

NOTE: New "current situation instructions" can be developed by varying the scenarios chosen in periods 2 through 5 when a number of the players are playing the game for the second time. To do this, choose a sequence of scenarios other than those contained in these instructions and prepare a short explanation for each time period of why one scenario is replaced by another. The players continue to use tables 1, 2, and 3 to determine productivity levels and minimum outputs.

Table 4–*Current situation minimum output requirements*

Period	Scenario	Camping	Primitive recreation activities	Skiing	Timber harvest	Spiritual value
		—— Thousand visitor days/year		*——*	*Million bd. ft (total for period)*	*Acres of high value*[1]
1	All	[illegible]	20	20	180	15,000
2	2	22	25	40	180	15,000
3	2 or 3	34	33	60	180	22,000
4	4	28	20	35	270	15,000
5	4	34	15	40	270	15,000

2 acres of medium spiritual value equal 1 acre of high value.

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Proceedings of the

Symposium on Dwarf Mistletoe Control Through Forest Management

April 11-13, 1978, Berkeley, California

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Hemlock Dwarf Mistletoe

GENERAL TECHNICAL
REPORT PSW- 31

Proceedings of the Symposium on Dwarf Mistletoe Control Through Forest Management, April 11-13, 1978, Berkeley, California

Robert F. Scharpf John R. Parmeter, Jr.
Technical Coordinators

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Pacific Southwest Forest and Range Experiment Station
P.O. Box 245
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Scharpf, Robert F., and John R. Parmeter, Jr., tech. coords.
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These Symposium papers cover bases of control, control planning and decisionmaking, control operations and accomplishments, refining and improving control techniques, and pest damage and integrated control. A program summary and a list of literature references on the dwarf mistletoes are included.

Oxford: 412:442.1:176.1 *Arceuthobium campylopodum.*
Retrieval Terms: dwarf mistletoe; silvicultural control; disease control; control systems.

PREFACE

Dwarf mistletoes have long been recognized as among the most damaging diseases of conifers in western North America. Since the early 1900s, research and experimental management to control dwarf mistletoes have occupied the time of many workers in State, Provincial and Federal agencies of Canada and the United States. This effort has produced a voluminous literature and a fund of experience and observation of value to forest managers. Information, however, is scattered widely through the literature, stored in office archives, or carried in the heads of workers. In these forms, it is not always readily accessible or suitably organized for use by managers.

This Symposium, held in Berkeley, California, April 11-13, 1978, was designed to bring together current knowledge and experience in dwarf mistletoe control, with emphasis on forest management. The five sessions covered (a) the biological and silvicultural information on which control procedures are based; (b) the methods of collecting and applying information essential to control planning and decisionmaking; (c) the mechanics of control operations and assessment of accomplishments; (d) the needs for refining and improving control techniques; and (e) the integration of dwarf mistletoe control with other pest control and silvicultural requirements in stand management.

To speed up the publication of Symposium Proceedings, we decided to have each author assume full responsibility for submitting manuscripts in photoready format by the time the conference convened. The views expressed in each paper are those of the author and not necessarily those of the sponsoring organizations. Trade names are used solely for necessary information and do not imply endorsement by the sponsoring organizations.

We thank the many people who assisted in this Symposium. Julie Hart, Joan Green, Shirley Ramacher, and Johann and Nancy Bruhn helped in making local arrangements. Richard Clark, Marcia Wood, and illustrators from the Rocky Mountain Forest and Range Experiment Station and the Forest Service's Rocky Mountain and California Regions put together the visual aids. And finally we thank the speakers and panel moderators, who willingly gave their time and effort in the preparation and presentation of symposium papers, and the many participants whose questions and comments contributed much to the spirited discussion and exchange of ideas.

Robert F. Scharpf, Forest Service, U.S. Department of Agriculture
Co-chairman
J. R. Parmeter, Jr., University of California, Berkeley
Co-chairman
David B. Drummond, Forest Service, U.S. Department of Agriculture
General Secretary
Arthur H. McCain, University of California, Berkeley
Local Arrangements Chairman

Speakers at the Symposium on Dwarf Mistletoe Control Through Forest Management held in Berkeley, California, April 11-13, 1978:**Front Row** *(Left to right):* Frank G. Hawksworth, Robert F. Scharpf, James S. Hadfield, Charles L. Bolsinger, Oscar J. Dooling, Donald M. Knutson, Kenelm W. Russell, James L. Stewart, David B. Drummond, James W. Walters. **Back Row** *(Left to right):* James W. Byler, J. R. Parmeter, Jr., Phil Guthrie, G. A. Van Sickle, Robert W. Harris, Carleton B. Edminster, R. Duane Kingsley, Richard S. Smith, Jr., Lewis F. Roth, John G. Laut, Wilfred L. Freeman, Jr., Philip H. Intorf, S. J. Muraro, Ed F. Wicker.

Introduction

OPENING REMARKS[1/]

Robert F. Scharpf[2/]

Ladies and gentlemen, welcome to Berkeley and to this first symposium on dwarf mistletoes, "Dwarf Mistletoe Control Through Forest Manage-Ment." It gives me a great deal of pleasure to be here and to be a part of this program. As many of you already know, I have been involved in research aimed at the control of these parasitic plants for about two decades now, and it is a distinct honor and privilege for me to be co-chairing this symposium with my close friend and working colleague, Dr. J. R. Parmeter.

It gives me great pleasure to see the marvelous attendance we have received for this week's program. It shows to me that the forest manager and scientist, the teacher and administrator, or more simply put, the various people concerned with the management and well being of the forest are here to exchange knowledge and work in concert towards the solution of one of the West's most serious forest disease problems.

As the title of this symposium implies, the program is aimed at dwarf mistletoe control through forest management. This is not a research symposium on dwarf mistletoes--let me say again--this is not a research symposium on dwarf mistletoes; even though research scientists will play a prominent role in the program. This is a gathering not only of scientists but also of forest managers and practitioners who have valuable information, experience, and ideas to contribute to the topic of dwarf mistletoe control. I feel confident that they will take us further down the road towards a better understanding of these serious forest disease agents and how they can ultimately be brought under control.

For my final statement, let me point out that this is a symposium, which is a very special type of meeting. I think the term symposium as defined in Webster's Third New International Dictionary will describe what I judge will be the general tenor of this meeting. SYMPOSIUM: (1) "A drinking party; especially one following a banquet and providing music, singing and conversation, or a banquet or other social gathering at which there is a free interchange of ideas." (2) "A meeting at which several speakers deliver short addresses on related topics or on various aspects of the same topic or a collection of opinions on a subject especially one assembled and one published by a periodical."

Now I don't expect this group to adhere to the literal definition as just stated although I have a feeling, particularly among some of you I know quite well, that you won't deviate too far from at least one or two points of the before mentioned definition. What I do hope that you will keep in mind is that this symposium is to be an informal, open exchange of opinions, information, and ideas. We are not gathered here this week merely to receive information.but to share it.

[1/] Presented at the Symposium on Dwarf Mistletoe Control Through Forest Management, Berkeley, California, April 11-13, 1978.

[2/] Plant Pathologist, Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Berkeley, Calif.

OVERVIEW OF THE DWARF MISTLETOE PROBLEM[1]

James L. Stewart[2]

Abstract: Dwarf mistletoe is still the major disease problem in the Western United States. A simple approach to control based solely on pathology considerations is no longer compatible with the complexities of forest management. The development of simulated-yield models has been the most significant research during the past 15 years. This symposium is designed to present the most up-to-date knowledge and technology, and to indicate the needs for future research.

Why a symposium on dwarf mistletoe? Fifteen years ago, and much longer ago than that, when I started as a forest pathologist in Forest Pest Control, we knew how to control this pest. Research had provided the following information: Dwarf mistletoe was an obligate parasite, meaning that it could exist only on a living host. It was relatively host specific. Its spread into new stands was rapid near infected overstory trees but slow from tree to tree in an even-canopied stand. Mistletoe vigor improved when overdense stands were thinned, but from a practical standpoint, it was impossible to prune out 100 percent of the infections or otherwise completely sanitize an infested stand.

Based on this information the approach to control was quite simple: Infested stands at harvest were to be clearcut with complete destruction of residual whips. Younger infested stands could be thinned but only with complete discrimination against dwarf mistletoe, and the stocking was to be reduced just enough to improve tree growth but not stimulate the mistletoe. In mixed stands, those tree species that were immune or resistant to the dwarf mistletoe species were encouraged.

If we knew all these things that many years ago, why is there still so much confusion about how to deal with this pest. Why is dwarf mistletoe still the major disease problem in the West, causing an estimated annual loss of 3.2 billion board feet of timber? Why are we attending a symposium on dwarf mistletoe?

I think there are three main reasons:

One, the simplified approach to control is no longer compatible with the complexities of forest management. For example, in the past the approach was to clearcut large square or circular blocks and place sale boundaries in uninfested portions of adjacent stands or against natural barriers such as open fields or roads. In today's world, esthetics and other factors--not dwarf mistletoe--dictate location, shape, and size of clearcuts. If a pathologist recommended simply clearcutting today, the forest manager would likely come back and say, "I can't clearcut. Isn't there a way to satisfy both esthetics and reduction of mistletoe-caused impacts?"

Another example of increased complexities is the current role of economics in decision-making. Our approach to control was based primarily on silvicultural considerations. Now it is necessary to refine these considerations with economic evaluations. The forest manager must consider which treatment provides the best benefit-cost ratio. Should he thin a stand now or let it go until final harvest? To answer questions such as this, it is not enough to know that thinning will increase the vigor of dwarf mistletoe as well as tree vigor. The forest manager needs quantitative information on the interaction between increased tree growth and dwarf mistletoe intensification. Will the trees grow fast enough to compensate for the dwarf mistletoe impact and warrant the thinning investment?

Another situation might be this: A forester is faced with a mature infested stand and wants to harvest it. Given the species and the site, he knows he can achieve natural regeneration at much less cost than for clearcutting and planting. Fifteen years ago, pathologists would have said "no" to natural regeneration because the new trees would become infected from the overstory. I think most of us still say that regeneration in the absence of any infected overstory is best. But economics now force the question of how long can infected seed trees be left before significant infection of the new trees occurs. Maybe natural regeneration with the chance of some dwarf mistletoe is more cost-effective in the long run than artificial regeneration and the assurance of no dwarf mistletoe.

---

[1] Presented at the Symposium on Dwarf Mistletoe Control Through Forest Management, Berkeley, Calif. April 11-13, 1978.

[2] Director of Forest Insect and Disease Management Staff, State and Private Forestry, Forest Service, U.S. Dep. Agric., Washington, D.C.

The second major reason we are attending a dwarf mistletoe symposium is that over the past 15 years, spurred on by the need for refined information, research has produced significant new information and technology. The main purpose of this symposium is to present this new information to you. I want to highlight a few items. From a dwarf mistletoe standpoint, the most significant research over the past 15 years has been the progress in quantifying spread and intensification in managed stands, correlating levels of infection with growth impact, developing simulated stand yield programs, and incorporating mistletoe intensification and impact information into these simulations. The result is a simulated yield program or model for dwarf mistletoe infested stands. More research is needed to develop these models for additional host-parasite combinations and refine those now in existence. However, at least for ponderosa pine in the Southwest and lodgepole pine in the Central Rockies, the forest manager can use these computerized simulated-yield programs to compare the effects of dwarf mistletoe in a given stand under various management schemes. He can determine which scheme, varying from doing nothing to clearcutting and planting, will maximize yields and benefits or provide the best benefit-cost.

I am excited about this approach to pest management decisionmaking because it provides us with the needed tool to deal with the complexities in forest management in today's world. Dwarf mistletoe research personnel can be proud of this development. It is the outstanding operational example in pest management of a decisionmaking tool that integrates stand growth dynamics and pest population dynamics and impacts.

So the second major reason we are here is to receive an updating on new technology and control techniques, and maybe more importantly in evaluation and decisionmaking techniques.

The third reason we are here is because the job of transferring technology from the researcher to the user has not been receiving sufficient emphasis. Training forest managers in the rationale for dwarf mistletoe control and the technology for accomplishing it must be accelerated and this symposium is the beginning.

I would like to quote from a paper Duane Kingsley, whom you will hear later, presented to the Western International Forest Disease Work Conference in September 1976. Duane was talking about getting research into practice and he says, "I believe you will find the progress is more a crawl than a stampede and it will remain so until we can answer the following questions: Where should I do something and what is it that needs to be done? Why should it be done? What can I expect to happen if it doesn't get done? Where should I do nothing? Why?"

What I find disappointing is that we know the answers to these types of questions for many situations and have the technology to help the manager; we just haven't got the job done.

Duane goes on to say, "The managing forester needs to know the basic facts and how to design his own treatment prescription for each stand. With a few exceptions, I believe there are sufficient technical data on dwarf mistletoe for anyone who wants to dig them out. But there is a decided lack of state-of-the-art, practical guidelines on what to do about the problem. Salesmanship! Where is the pamphlet that I can hand to the District Ranger that tells him how to size up the problem, how to solve it and what will happen if he doesn't? Where is the group training package, the slide tape program, or self training aid designed for a group or a new forester to bring their skill level up to standard?"

So we are having this symposium because many of the simplistic approaches are now out of date with today's complex forest management, research has provided new information and new technology, and a symposium is a good way to start an accelerated effort to transfer this knowledge to you. But I would like to add that a symposium is only the beginning. You as forest managers are responsible for managing the forests under your jurisdiction in the most efficient and productive manner that you can, commensurate with your prescribed management objectives. This requires that you learn and apply new knowledge and technology as it becomes applicable to your situation. Research pathologists are responsible for providing new information and technology. Pest control specialists are responsible for training you in this new technology and helping you to apply it. But you and only you can actually apply new knowledge.

During this symposium you will be presented with the most up-to-date knowledge and technology, on the basis for control including biological factors of the parasite and forest stand dynamics, on decisionmaking, and on control planning and operations. There will be discussions on recent research and development activities in refining and improving control techniques, and finally on approaches to integrating dwarf mistletoe control into forest management. We expect this symposium to be followed by training sessions and updated guidelines for the control of dwarf mistletoe. Certainly there will be a continuing need for bringing you up to date as research aimed at your specific needs is accomplished. However I want to again stress one critical point. Symposiums, training sessions, and guidelines--although important--will not accomplish the reduction of dwarf mistletoe impacts on management objectives. Only the forest manager's application of the available technology can accomplish that.

The final topic in this symposium is "Needs for Further Research." I talked about the forest manager's obligation in applying new technology. He also has an obligation to identify and communicate his research needs. Unless he does this, there is no way we can have a viable, problem-solving research program designed to fill specific information gaps. This communication from the user to the researcher is especially critical in these times when funds for pathology research are few. If research administrators are to direct what few dollars there are to solving specific high-priority management problems, the forest manager must tell them what the specific problems are.

I think it is necessary for each of us to reflect every so often on what we may refer to as the total technology transfer system. In the case of dwarf mistletoe this involves the researcher, the pest management specialist, and the forest manager. If any one of these individuals does not do his part, the job does not get done. If the forest manager does not identify and communicate his research needs, then the researcher does not work on those needs. If the researcher is not responsive to the forest manager's needs, then the specific new knowledge is not provided. If the pest control specialist does not train and assist the forest manager, the new knowledge does not get transferred to the user, and if the forest manager does not apply the new knowledge, then the whole thing has been for naught and no improvements are made.

I hope each of you will keep this in mind during the symposium. Let your mental process dwell on practical situations and try to think through how you would handle them and apply what you are learning. If you come up against a question, let the question be known so that it can be answered or listed as a research need.

I look forward to these three days. Let us each learn and then go home and apply what we have learned.

Bases for Control

BIOLOGICAL FACTORS OF DWARF MISTLETOE IN RELATION TO CONTROL[1]

Frank G. Hawksworth[2]

Abstract: Dwarf mistletoes have been present in North American coniferous forests for essentially as long as their hosts. Most of the world's dwarf mistletoes occur in North America where they attack all six genera of the Pinaceae: Pinus, Picea, Abies, Larix, Tsuga, and Pseudotsuga. Dwarf mistletoes have many effects including: growth loss, mortality, reduction in seed crops, lowered wood quality, predisposition of infected trees to insects and fungi, and ecologic effects. Features that make the dwarf mistletoes amenable to silvicultural control measures are: they are obligate parasites so will live only as long as the host does; they are generally host specific; they have long life cycles, frequently 4 to 6 years; the rate of spread through stands is slow, generally on the order of 1 to 2 feet per year; and they are readily detected as they are non-microscopic organisms and cause distinctive symptoms.

INTRODUCTION

Dick Parmeter and I have been asked to help "set the stage" for this symposium by outlining some basics of dwarf mistletoe biology, stand dynamics, and ecological factors relating to control. I'll discuss the following items relating to biology and let Dick tackle the difficult topics of stand dynamics and ecological factors.

History
The genus Arceuthobium
Host relationships
Dwarf mistletoe effects
Dwarf mistletoe life cycles
Bases for control

HISTORY

The dwarf mistletoes are no newcomers to North America. We know from fossil evidence that these parasites have been here at least since the Miocene period, or about 25 million years. They presumably migrated across the Bering area from eastern Asia, along with their coniferous hosts. Thus, the dwarf mistletoes and Western conifers have co-evolved over the millenia. We must keep this in mind when we tend to regard mistletoes and other "pests" as something foreign to, and not an integral part of, forest ecosystems (Hawksworth 1975).

The earliest written record of dwarf mistletoe that I have found is from southern Europe (Clusius 1601). The first North American collection was by the famous explorer and naturalist Alexander von Humbolt, in Veracruz, Mexico, in 1804. David Douglas, the botanical explorer, was apparently the first to discover dwarf mistletoes in what is now the United States (Douglas 1914). In 1826 he found two dwarf mistletoes in eastern Washington, which we can now determine were Arceuthobium americanum on lodgepole pine, and A. campylopodum on ponderosa pine (although he thought the latter was red pine).

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[1] Presented at Symposium on Dwarf Mistletoe Control through Forest Management, Berkeley, Calif. April 11-13, 1978.

[2] Supervisory Forest Pathologist, Rocky Mountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Fort Collins, Colo.

Several early western botanists in the 1850's collected dwarf mistletoes which were sent to Dr. George Engelmann of the Missouri Botanical Garden, who described most of the species in the West. Dr. James R. Wier, pioneer forest pathologist in the Inland Empire from 1910 to 1923, was the first to point out the seriousness of the dwarf mistletoe problem in the coniferous forests of the West. Recognition of them as a serious problem in the West, however, was slow to develop. It took several early western Forest Pathologists--notably Lake S. Gill (who prepared a dwarf mistletoe monograph (Gill 1935)), Toby Childs, Willis W. Wagener, and J. S. Boyce--to bring about this awareness. These missionary pathologists helped show that not only were these parasites causing severe losses in the West, but more importantly, that the dwarf mistletoes could be controlled by silvicultural means. They, in fact, helped build the strong foundation on which this symposium was constructed.

THE GENUS ARCEUTHOBIUM

The dwarf mistletoes are unique as the only group of parasitic higher plants confined to conifers. They occur on conifer branches or stems, and their endophytic (or root) system is embedded in bark and wood tissues of the host (fig. 1).

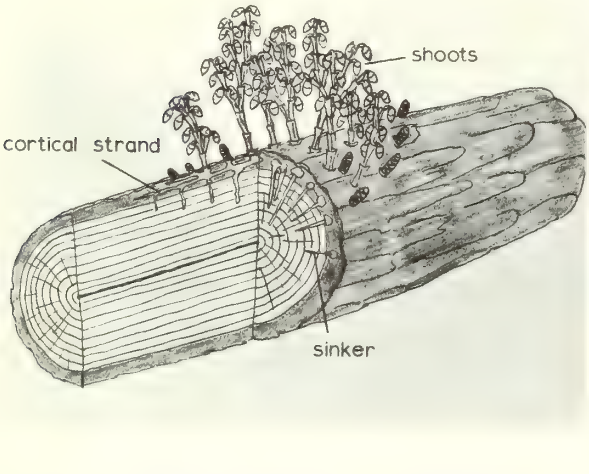

Figure 1--Dwarf mistletoe in a pine stem--showing shoots, cortical strands and sinkers.

The aerial parts of the dwarf mistletoe (the shoots) are essentially reproductive structures. The shoots range from as small as 1/4 inch high in Arceuthobium minutissimum of the Himalayas to as high as nearly 3 feet for A. globosum in Guatemala, but most species have shoots from 3 to 5 inches high. Dwarf mistletoe color ranges from black to red, purple, green, gray, brown, to yellow (Hawksworth and Wiens 1973). The root system consists of two main parts: (1) the cortical strands which occur primarily longitudinally in the inner bark, and (2) the sinkers, which extend from the cortical strands radially into ray tissues of the host xylem. The sinkers, which become imbedded in the xylem as the host tissues grow around them, provide the mechanism for water conduction from host to parasite tissues (Kuijt 1960).

The dwarf mistletoes contain chlorophyll so they can manufacture some of their carbohydrates, but they obtain most of their carbohydrates and all of their water and minerals directly from the host. In contrast to most mistletoes, carbohydrates manufactured by dwarf mistletoes are not translocated to the host (Leonard and Hull 1965).

Arceuthobium, the only genus that occurs in the eastern and western hemispheres, comprises some 31 known species. A few of these have recognizable subspecies on host forms so the grand total is now 38 dwarf mistletoes (table 1). This is six more than we knew of when we published our monograph 6 years ago (Hawksworth and Wiens 1972).

North America has the "lion's share" of the world's dwarf mistletoes--32 of the known 38. Most of these occur in Mexico and in the Western United States. The taxonomic status of the dwarf mistletoes, as indeed many of their host trees, is not yet "finalized." Several unsettled questions remain, e.g.; (1) the taxonomic status and host relationship of A. campylopodum and A. occidentale in California; (2) the status of dwarf mistletoes on white pines in northern California and southern Oregon, and (3) the status of "races" of the hemlock dwarf mistletoe--A. tsugense. It now seems fairly sure that A. tsugense has at least two "races" (Smith and Wass 1976) --one on shore pine in coastal British Columbia, Vancouver Island and Orcas Island, Washington, and one on western hemlock from Alaska to California. Possibly, the populations on mountain hemlock also are distinct.

Table 1--Synopsis of the genus *Arceuthobium*, with distribution and principal hosts of each taxon.

Dwarf Mistletoe	Distribution	Principal hosts
NEW WORLD TAXA		
1. *Arceuthobium abietinum*		
a. f. sp. *concoloris*	Western U.S.	*Abies concolor*
b. f. sp. *magnificae*	Calif., S. Oreg.	*Abies magnifica*
2. *Arceuthobium abietis-religiosae*	Mexico	*Abies spp.*
3. *Arceuthobium americanum*	West. U.S., West. Can.	*Pinus contorta*, *P. banksiana*
4. *Arceuthobium apachecum*	SW U.S.	*Pinus strobiformis*
5. *Arceuthobium aureum*		
a. Subspecies *aureum*	Guatemala, Belice	*Pinus* spp.
b. Subspecies *petersonii*	S. Mexico	*Pinus* spp.
6. *Arceuthobium bicarinatum*	Hispaniola	*Pinus occidentalis*
7. *Arceuthobium blumeri*	Ariz., Mexico	*Pinus strobiformis*
8. *Arceuthobium californicum*	Calif., Oreg.	*Pinus lambertiana*
9. *Arceuthobium campylopodum*	W. U.S., Mexico	*Pinus ponderosa*, *P. jeffreyi*
10. *Arceuthobium cyanocarpum*	W. U.S.	*Pinus flexilis*
11. *Arceuthobium divaricatum*	W. U.S., Mexico	Pinyons
12. *Arceuthobium douglasii*	B.C., W. U.S., Mexico	*Pseudotsuga menziesii*
13. *Arceuthobium gillii*		
a. Subspecies *gillii*	SW U.S., Mexico	*Pinus leiophylla*
b. Subspecies *nigrum*	Mexico	*Pinus* spp.
14. *Arceuthobium globosum*		
a. Subspecies *globosum*	Mexico	*Pinus* spp.
b. Subspecies *grandicaule*	Mexico, Guatemala	*Pinus* spp.
15. *Arceuthobium guatemalense*	Mexico, Guatemala	*Pinus ayacahuite*
16. *Arceuthobium hondurense*	Honduras	*Pinus oocarpa*
17. *Arceuthobium laricis*	B.C., NW U.S.	*Larix occidentalis*
18. *Arceuthobium microcarpum*	Ariz., N. Mex.	*Picea engelmannii*, *P. pungens*
19. *Arceuthobium occidentale*	Calif.	*Pinus sabiniana*, *P. radiata*
20. *Arceuthobium pusillum*	E. Can., E. U.S.	*Picea mariana*, *P. glauca*
21. *Arceuthobium rubrum*	Mexico	*Pinus* spp.
22. *Arceuthobium strictum*	Mexico	*Pinus* spp.
23. *Arceuthobium tsugense*		
a. Western hemlock race	Alaska to Calif.	*Tsuga heterophylla*
b. Shore pine race	B.C., NW Wash.	*Pinus contorta*
24. *Arceuthobium vaginatum*		
a. Subspecies *vaginatum*	Mexico	*Pinus* spp.
b. Subspecies *cryptopodum*	Colo., Utah to Mexico	*Pinus ponderosa*
c. Subspecies *durangense*	Mexico	*Pinus* spp.
25. *Arceuthobium verticilliflorum*	Mexico	*Pinus* spp.

OLD WORLD TAXA

26.	Arceuthobium azoricum	Azores	Juniperus brevifolia
27.	Arceuthobium chinense	SW China	Abies sp., Keteleeria sp.
28.	Arceuthobium juniperi-procerae	Central Africa	Juniperus procera
29.	Arceuthobium minutissimum	India, Pakistan	Pinus wallichiana
30.	Arceuthobium oxycedri	Spain to India	Juniperus spp.
31.	Arceuthobium pini	SW China	Pinus tabulaeformis

HOST RELATIONSHIPS

The dwarf mistletoes parasitize all six genera in the Pinaceae in North America: Pinus, Picea, Abies, Larix, Pseudotsuga and Tsuga. Most dwarf mistletoes parasitize pines as their principal hosts:

Principal Hosts	Number of Dwarf Mistletoes
Hard pines	18
White pines	6
True firs	3
Spruce	2
Hemlock	1
Larch	1
Douglas-fir	1

Junipers are the primary hosts in the Old World (3 of the 6 species) but this group is not parasitized by Arceuthobium in the New World, although the related genus Phoradendron is common on junipers here. Other conifers of the families Cupressaceae and Taxodiaceae (Cupressus, Chamacyparis, Taxodium, Taxus, Thuja, Sequoia, and Sequoiadendron) are not parasitized by the dwarf mistletoes. Perhaps that is why some of them are so long lived!

An important consideration for control is that dwarf mistletoes are generally host specific--that is, they are usually confined to a single host species or a group of closely related species. The dwarf mistletoes of the principal conifers of Western United States and Canada are listed in Table 2.

DWARF MISTLETOE EFFECTS

The effects of dwarf mistletoes on their hosts fall into six major kinds, which will be noted briefly here, but will be discussed in more detail by subsequent speakers.

I emphasize that we're talking about dwarf mistletoe "effects", which may or may not be causing an "impact" on the forest resource. This, too, will be discussed in more detail by the next speaker.

Growth Loss

The most common result of dwarf mistletoe infection is reduction of growth rates of infected trees. The degree of reduction depends on the intensity of infection. It ranges from essentially no measurable effect in lightly infected trees to severe reduction in heavily infected trees. In general, height growth is more seriously affected than diameter growth for a given degree of infection. In many forest types, growth loss is the primary mistletoe-loss factor (I'd place lodgepole pine, coastal ponderosa pine, western hemlock, etc., in this category.)

Mortality

Although it is often not realized by foresters, dwarf mistletoes can kill trees directly. The more common situation, however, is that dwarf mistletoes so seriously reduce the vigor of trees that they are "finished off" by secondary insects. The extent of mortality is very variable depending on the host/parasite combination, stand age, site factors, etc. For example, mortality accounts for a relatively small proportion of the total dwarf mistletoe-caused loss in coastal ponderosa pine but it is a much more significant loss factor in Southwestern ponderosa pine. Mortality is also particularly severe in infested Douglas-fir stands.

Table 2. Dwarf mistletoes of the principal conifers in the Western United States.

Host	Dwarf mistletoes common throughout most of the ranges of the host	Dwarf mistletoes locally common
Abies amabilis	*A. tsugense*	-
Abies concolor	*A. abietinum* f. sp. *concoloris*	-
Abies grandis		*A. abietinum* f. sp. *concoloris*
Abies magnifica	*A. abietinum* f. sp. *magnificae*	-
Larix occidentalis	*A. laricis*	-
Picea engelmanni		*A. microcarpum*
Picea pungens		*A. microcarpum*
Pinus aristata		*A. microcarpum* *A. cyanocarpum*
Pinus attenuata		*A. campylopodum* *A. occidentale*
Pinus contorta		
subsp. *contorta*		*A. tsugense*
subsp. *murrayana*	*A. americanum*	-
subsp. *latifolia*	*A. americanum*	-
Pinus coulteri		*A. occidentale* *A. campylopodum*
Pinus edulis	*A. divaricatum*	-
Pinus flexilis	*A. cyanocarpum*	-
Pinus jeffreyi	*A. campylopodum*	-
Pinus lambertiana	*A. californicum*	-
Pinus longaeva	*A. cyanocarpum*	-
Pinus monophylla	*A. divaricatum*	-
Pinus monticola		*A. tsugense* *A. californicum*
Pinus muricata		*A. occidentale*
Pinus ponderosa		
var. *ponderosa*	*A. campylopodum*	-
var. *scopulorum*	*A. vaginatum* subsp. *cryptopodum*	*A. americanum*
Pinus radiata	*A. occidentale*	-
Pinus sabiniana	*A. occidentale*	-
Pinus strobiformis	*A. apachecum*	*A. blumeri*
Pseudotsuga menziesii	*A. douglasii*	-
Tsuga heterophylla	*A. tsugense*	-
Tsuga mertensiana	*A. tsugense*	*A. laricis*

Seed Crops

Although we have little quantitative data, the evidence is that heavily infected trees produce both fewer seeds and seeds of lower viability (Korstian and Long 1922, Munns 1919). Because of this, heavily infected trees should not be left as seed trees.

Effects on Wood

The anatomy of host wood in dwarf mistletoe bole infections is markedly altered. Affected wood has shorter and distorted tracheids and a greatly increased proportion of ray tissue, so strength and pulping characteristics are reduced (Piirto et al. 1974, Hunt 1971). The practical significance of the strength reduction has not been determined, but it is presumably slight (Dobie and Britneff 1975, Wilcox et al. 1973). Most mistletoe-affected wood is near the outside of the bole and would tend to be removed in slabbing. Another marked, but again not quantified, effect of dwarf mistletoe is the increased size of knots in wood.

Predisposition to Insects and Fungi

Under "Mortality" I mentioned that dwarf mistletoes typically weaken trees so that they are more susceptible to attack by insects, particularly bark beetles. In some situations this may not only result in death of infected trees, but beetle populations may build up and spread out to adjacent non-mistletoe stands. The interaction between dwarf mistletoes and bark beetles is far from understood, and needs to be evaluated (Stevens and Hawksworth 1970, Parker and Stipe 1970, Johnson et al. 1976). In firs and hemlock, old bole infections, particularly those with exposed wood, may provide entrance points for decay fungi (Etheridge 1973). However, this is apparently not a factor in pines, spruce, or Douglas-fir--presumably because of the higher resin content of these trees.

Ecologic Effects

Dwarf mistletoes can have profound ecologic effects on forest stands. As will be discussed later in the symposium, wildfires have been the primary controlling factors of the dwarf mistletoes in the past. It is often not recognized that dwarf mistletoes may also affect fire hazard conditions in infested stands because the dead trees, lower limbs, etc., are more flammable. Also, dwarf mistletoes are intimately involved in forest succession and change of species composition in several types (see Wicker, these proceedings).

DWARF MISTLETOE LIFE CYCLES

I'll briefly outline the life cycles of dwarf mistletoes with emphasis on how they relate to control. I'll hope to pinpoint "weak links" to show the most susceptible points for interference with the life cycle.

Flowering

The male flowers in Arceuthobium are 2-3 mm across and typically 3- or 4-parted (fig. 2).

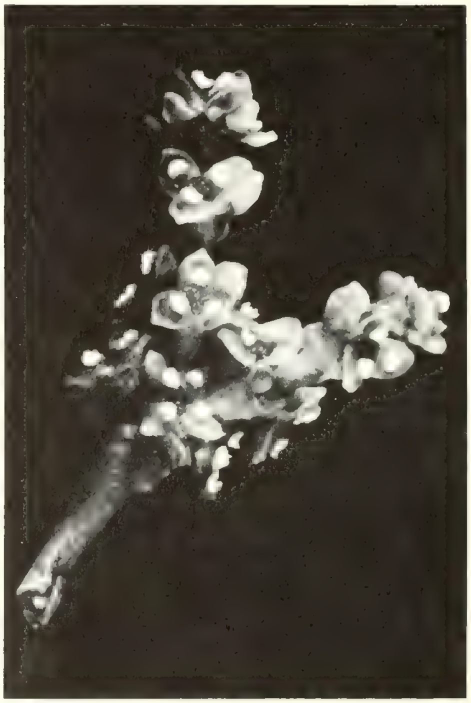

Figure 2--Male dwarf mistletoe flower.

Each segment has a single sessile anther, containing 1,000 to 4,000 yellow pollen grains. The center of each flower contains an organ which we interpret as a nectary. The female flowers are only 1-2 mm long and are very inconspicuous (fig. 3). They, too have a nectary which is attractive to insects.

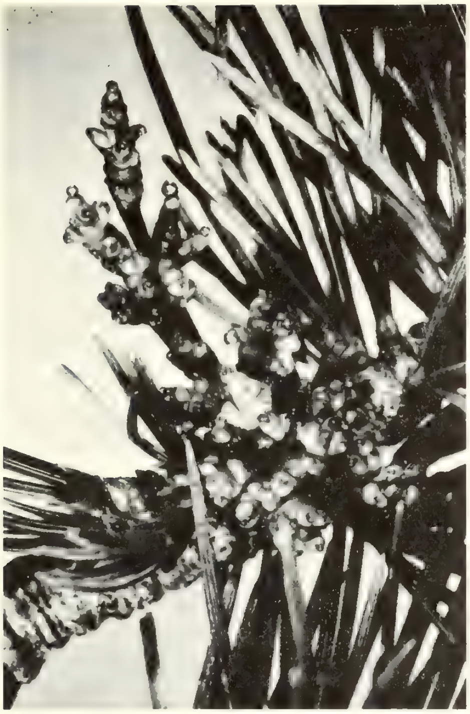

Figure 3--Female dwarf mistletoe flower.

All the dwarf mistletoes are dioecious--that is, the male and female flowers occur on separate plants. All the Western United States and Canadian species studied to date show a sex ratio of approximately 1:1. However, some Mexican species seem to show a preponderance of female plants.

In general, the North American mistletoes fall into two main flowering groups--those that flower in the spring: *A. americanum*, *A. pusillum*, *A. douglasii*, *A. vaginatum*, and *A. gillii*--and those that flower in summer or fall: *A. abietinum*, *A. apachecum*, *A. blumeri*, *A. californicum*, *A. campylopodum*, *A. cyanocarpum*, *A. divaricatum*, *A. laricis*, *A. microcarpum*, *A. occidentale*, and *A. tsugense*.

Peak flowering in most species usually is confined to a 2- to 4-week period. The period is generally confined to a certain time of the year, depending on the species, but may vary somewhat from year to year due to climatic variation.

There is mounting evidence that the dwarf mistletoes are pollinated both by insects and by wind (Penfield et al. 1976). While both agents are probably involved to some extent in all species, either insects or wind seem to be the primary agent in particular species.

Seed Maturity and Dispersal

The length of the seed maturation period ranges from as little as 5 months in the eastern dwarf mistletoes, *A. pusillum*, to 18 months in some Mexican species. For most species, this period averages from 12 to 14 months. Seeds of the dwarf mistletoes mature in the late summer or fall (July to November) depending on the species.

The dwarf mistletoes have a unique, explosive seed dispersal mechanism. At maturity, the single seed is forcibly ejected from the fruit (figs. 4, 5) at initial velocities of 80 to 90 feet per second (60 miles per hour) (Hinds and Hawksworth 1965).

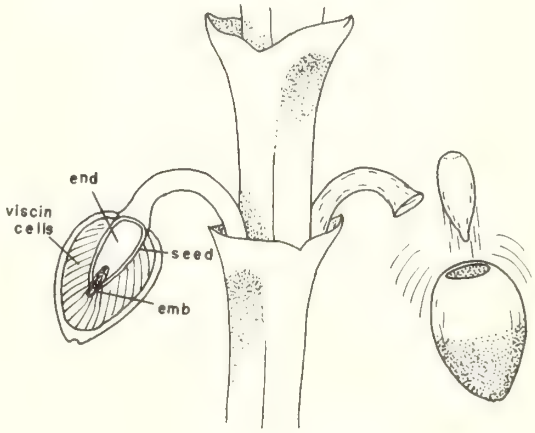

Figure 4--Diagrammatic view of the dwarf mistletoe seed expulsion mechanism. Left.--A mature fruit before the seed is expelled, showing how the pedicel of the fruit is elongated and recurved so that the original apex of the fruit is now pointed downward. The gross anatomy of the fruit showing the seed, embryo, endosperm, and viscin cells. Right.--A mature fruit immediately after the discharge of the seed. The fruit is severed from the pedicel and the seed is ejected from the fruit and propelled upwards.

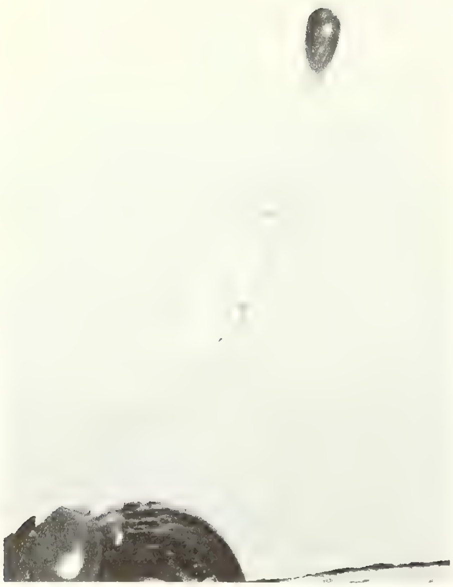

Figure 5--Seed discharge in Arceuthobium.

The distance of seed flight depends on several factors such as height of the source plant, angle of seed discharge, wind velocity, stand density, etc.

The seeds as they leave the fruit tend to be hurled upward (usually at angles of 30 to 40 degrees above the horizontal (Hawksworth 1961, Strand and Roth 1975)). Seeds that are expelled at lower angles fly further horizontally (fig. 6).

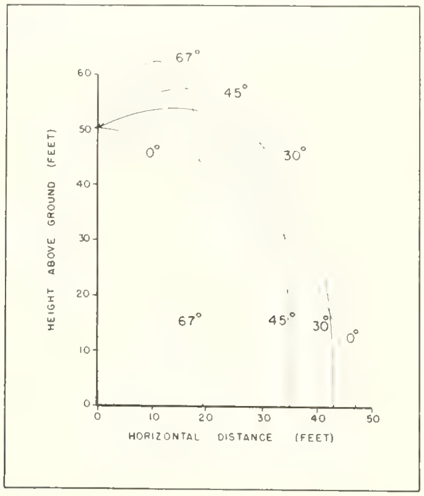

Figure 6--Trajectories of seeds expelled at various angles.

The relationship between number of seeds dispersed and distance from source plant is shown for Arceuthobium vaginatum in ponderosa pine (fig. 7).

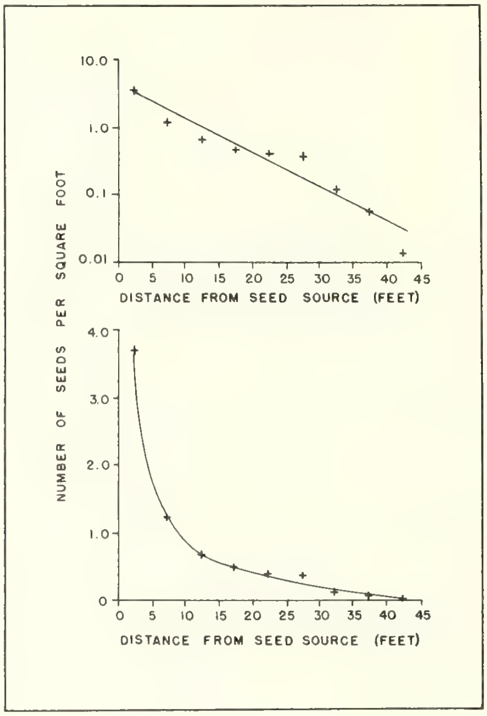

Figure 7--Relationship between seed density and distance from source. Arceuthobium vaginatum on ponderosa pine in Arizona (Hawksworth 1961).

The average horizontal distance of seed flight is between 15 and 20 feet, but seeds will sometimes fly as far as 100 feet.

Studies in Colorado for dwarf mistletoe in ponderosa pine and lodgepole pine showed that from 4 to 11 seeds per square foot fall through to the forest floor (Hawksworth 1965). When allowances are made for the seeds that stick to the trees, the total number of seeds produced range from about 300,000 to 800,000 per acre per year. In one ponderosa pine stand, we found an average of 160 seeds per square foot on the forest floor; this is over 7 million seeds per acre--and accounts for only the seeds that missed the trees!

Little is known of long-distance dispersal of dwarf mistletoe seeds. However, studies in the Lake States, the Rocky Mountains and in the Northwest implicate birds (Hudler et al. 1974, Zilka and Tinnin 1976, Hudler et al. 1978) and squirrels (Lemons 1978). In our studies with Arceuthobium vaginatum on ponderosa pine in Colorado, we found isolated infection centers sometimes as far as 1/4 mile from the closest generally infested stands. Birds, mainly mountain chickadees and pygmy nuthatches, seem to be the primary vectors in this area. Long-distance dispersal, however, seems to be quite limited and, from a practical control standpoint, can probably be ignored.

Interception of Seeds by the Host

The seeds as hurled from the fruit are sticky and readily adhere to whatever they strike, providing their velocity is not too high. If they strike objects at close range at high velocity, they will rebound and perhaps land on another part of the potential host tree. Conifer needles, because of their high volume in the air space and their resilience, are very effective in intercepting seeds in flight.

Studies in a lodgepole pine and a ponderosa pine stand show that about 40 percent of the seeds produced are intercepted by the trees (Hawksworth 1965). Seeds usually remain on the needles until the fall rains, when the viscous coating swells and acts as a lubricant and the seeds slide down the needles toward the twigs (Roth 1959). If the particular needle does not form a high vertical angle with the twig then the seed may fall and be lost. In general, seeds must be transferred to within 0.5 cm of the twig for successful infection to take place.

Most infection takes place through the needle-bearing parts of the twig and the youngest growth is most susceptible. Needle-bearing twigs are usually 4-6 years old for pines but may be up to 20 years old for firs. Older tissues, generally, are not susceptible, except for *A. americanum* in lodgepole pine where infection can take place through trunk tissues up to 60 years old (Hawksworth 1954).

Germination and Infection

Most dwarf mistletoes germinate in the spring after overwintering on the needles or twigs. An exception is *A. vaginatum* on ponderosa pine which germinates in the fall soon after seed dispersal (Hawksworth 1961). The spring-germinating species contain a dormancy-inducing substance in the seed coat that slowly breaks down with time at temperatures near freezing (Beckman and Roth 1968). Germination rates are fairly high (often over 90 percent in the species that have been investigated).

In germination, the radicle of the seed grows along the host branch until it encounters an irregularity, such as the base of a needle, where a mound of tissue develops into the host cortex. This establishes the endophytic (or root) system of the mistletoe within the host.

Many seeds are lost due to various factors: insects, fungi, birds, washing off due to rain and snow, etc. (Wicker 1967). Studies are underway to determine the proportion of mistletoe seeds produced that produce new infections (Hawksworth 1965). We do not have firm figures yet, but the results to date indicate a success ratio of less than 5 percent, probably closer to 1 percent.

Incubation Period

The dwarf mistletoes have relatively long incubation periods--the time from germination to fruit maturity ranges from 4 to 6 years or more depending on the species (fig. 8).

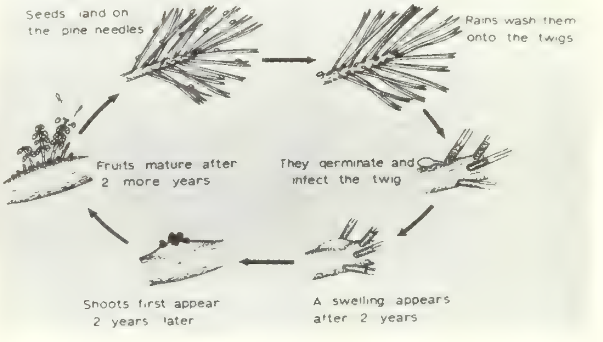
Seeds land on the pine needles
Rains wash them onto the twigs
They germinate and infect the twig
A swelling appears after 2 years
Shoots first appear 2 years later
Fruits mature after 2 more years

Figure 8--Life cycle diagram for a typical dwarf mistletoe.

Two to 3 years usually elapse before shoots emerge from the bark, making detection of incipient infections impossible.

Individual shoots live for 2 to 5 years although the endophytic system within the host lives for as long as the adjacent host tissues are alive and new shoots continue to arise. The endophytic system can live completely parasitically within the host without aerial shoots.

BASES FOR CONTROL

Several features of the dwarf mistletoes make them susceptible to cultural control methods as we will hear about in subsequent papers. But these form the basis for control:

1. The dwarf mistletoes are obligate parasites; that is, they need a living host to survive. Hence, once an infected tree or branch is cut, dwarf mistletoe is no longer a threat. There is no need to burn the slash as it is harmless from the mistletoe standpoint.

2. The dwarf mistletoes are generally host specific. That is, they are usually confined to one host or a group of closely related species. It is frequently possible to favor an immune or lightly infected tree species to minimize dwarf mistletoe damage.

3. The dwarf mistletoes have a long life cycle. The time from infection to seed production is typically 4-6 years and sometimes even longer. This is in marked contrast to most fungus diseases where the cycle may be a few weeks or, at most, a year. From a practical standpoint the long life cycle means that build-up of populations is relatively slow.

4. Dwarf mistletoes have a slow rate of spread. Due to the long life cycle, and other factors, spread of dwarf mistletoes is relatively slow. Spores of disease-causing fungi can be blown for miles but the range of dwarf mistletoe seeds is fairly limited. They may fly as far as 100 feet from an isolated tall tree, but their flight in even-aged stands is short. On the average, dwarf mistletoes progress through stands at about 1-2 feet per year, and occurrence is characteristically spotty.

5. Effects of dwarf mistletoes are readily visible. This may seem obvious, but it is important to keep in mind that we are working with a disease caused by a non-microscopic organism and one that is associated with distinct symptoms. Dwarf mistletoes are not like many forest diseases--e.g., root rots, foliage diseases, abiotic disorders--where the cause of the problem may be obscure. In dwarf mistletoe stands it is generally easy to detect diseased and healthy areas.

Thus, several features of the dwarf mistletoes render them amenable to control. We'll hope to show during the rest of the symposium how we can take advantage of these features to develop control strategies.

LITERATURE CITED

Beckman, K. M., and L. F. Roth
1968. The influence of temperature on longevity and germination of seed of western dwarf mistletoe. Phytopathology 58:147-150.

Clusius, Charles
1601. Caroli clusi at rebatis..rariorum plantarum historia. 364 p. Antwerp, Belgium.

Dobie, J., and A. A. Britneff
1975. Lumber grades and volumes from lodgepole pine infected with dwarf mistletoe. Wood and Fiber 7:104-109.

Douglas, David
1914. Journal kept by David Douglas during his travels in North America, 1823-1827. 364 p. Antiq. Press Ltd., New York.

Etheridge, D. E.
1973. Wound parasites causing tree decay in British Columbia. Can. Dep. Environ. For. Serv., Pacific For. Res. Cent. For. Pest Leafl. 62, 15 p.

Gill, L. S.
1935. Arceuthobium in the United States. Conn. Acad. Arts and Sci. Trans. 32:111-245.

Hawksworth, F. G.
1954. Observations on the age of lodgepole pine tissues susceptible to infection by Arceuthobium americanum. Phytopathology 44:552.

Hawksworth, Frank G.
1961. Dwarfmistletoe of ponderosa pine in the Southwest. U.S. Dep. Agric. Tech. Bull. 1246, 112 p.

Hawksworth, Frank G.
1965. Life tables for two species of dwarfmistletoe. I. Seed dispersal, interception, and movement. For. Sci. 11:142-151.

Hawksworth, Frank G.
1975. Dwarf mistletoe and its role in lodgepole pine ecosystems. In Management of lodgepole pine ecosystems. Symp. Proc. Wash. State Univ., D. A. Baumgartner, editor. Vol. 1:342-358.

Hawksworth, F. G., and D. Wiens
1972. Biology and classification of dwarf mistletoes (Arceuthobium). U.S. Dep. Agric., Agric. Handb. 401, 234 p.

Hinds, T. E., and F. G. Hawksworth
1965. Seed dispersal velocity in four dwarfmistletoes. Science 148:517-519.

Hudler, G. W., F. G. Hawksworth, and N. Oshima.
1978. Bird dispersal of southwestern dwarf mistletoe in Colorado. Am. Midl. Nat. [In press]

Hudler, G., T. Nicholls, D. W. French, and G. Warner.
1974. Dissemination of seeds of the eastern dwarf mistletoe by birds. Can. J. For. Res. 4:409-412.

Hunt, K.
1971. A comparison of Kraft pulping of sound and dwarf mistletoe-infected western hemlock wood. Can. Dep. Fish. and For., For. Products Lab., Vancouver, Inf. Rep. VP-X-78, 7 p.

Johnson, D. W., L. C. Yarger, C. D. Minnemeyer, and V. E. Pace
1976. Dwarf mistletoe as a predisposing factor for mountain pine beetle attack of ponderosa pine in the Colorado front range. U.S. For. Serv., Rocky Mt. Reg., For. Insect and Dis. Manage. Tech.Rep. R2-4, 7 p.

Korstian, C. F., and W. H. Long
1922. The western yellow pine mistletoe: effect on growth and suggestions for control. U.S. Dep. Agric. Bull. 1112, 35 p.

Kuijt, Job.
1960. Morphological aspects of parasitism in the dwarf mistletoes (Arceuthobium). Univ. Calif. Publ. Bot. 30:337-436.

Lemons, Daniel E.
1978. Small mammal dissemination of dwarf mistletoe seeds. M.S. thesis, Portland State Univ., Portland, Oregon, 38 p.

Leonard, O. A., and R. J. Hull
1965. Translocation relationships in and between mistletoes and their hosts. Hilgardia 37:115-153.

Munns, E. N.
1919. Effect of fertilization on the seed of Jeffrey pine. Plant World 22:138-144.

Parker, Douglas L., and Lawrence E. Stipe.
1974. Does the mountain pine beetle select and kill dwarf mistletoe-infected lodgepole pine? Insect and Dis. Control. State and Priv. For. Reg. 4, For. Serv., U.S. Dep. Agric., Ogden, Utah. 12 p.

Penfield, F. B., R. E. Stevens, and F. G. Hawksworth.
1976. Pollination ecology of three Rocky Mountain dwarf mistletoes. For. Sci. 22:473-484.

Piirto, Douglas D., Donald L. Crews, and Harry E. Troxell.
1974. The effects of dwarf mistletoes on the wood properties of lodgepole pine. Wood and Fiber 6:26-35.

Roth, Lewis F.
1959. Natural emplacement of dwarfmistletoe seed on ponderosa pine. For. Sci. 5:365-369.

Smith, R. B., and E. F. Wass
1976. Field evaluation of ecological differentiation of dwarf mistletoe on shore pine and western hemlock. Can. J. For. Res. 6:225-228.

Stevens, Robert E., and Frank G. Hawksworth
1970. Insects and mites associated with dwarf mistletoes. USDA For. Serv. Res. Pap. RM-59, 12 p., Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Strand, M. A., and L. F. Roth
1976. Simulation model for spread and intensification of western dwarf mistletoe in thinned stands of ponderosa pine saplings. Phytopathology 66:888-895.

Wicker, Ed F.
1967. Seed destiny as a klendusic factor of infection and its impact upon propagation of Arceuthobium spp. Phytopathology 57:1164-1168.

Wilcox, W. Wayne, W. Y. Pong, and J. R. Parmeter
1973. Effects of mistletoe and other defects on lumber quality in white fir. Wood and Fiber 4:272-277.

Zilka, Paul J., and Robert O. Tinnin
1976. Potential avian influences in the distribution of dwarf mistletoe. Northwest Sci. 50:8-16.

FOREST STAND DYNAMICS AND ECOLOGICAL FACTORS IN RELATION TO DWARF MISTLETOE SPREAD, IMPACT, AND CONTROL[1]

J. R. Parmeter, Jr.[2]

Abstract: Dwarf mistletoes are markedly host specific, perennial, obligate parasites. The success of mistletoe populations is tied not only to the suitability of the environment, but also to the availability and conditions of the hosts they infect. Thus, the dynamics of forest stand development and change exert major influences on the capacity of dwarf mistletoes to spread, intensify, and cause damage to host trees. Silvicultural control of dwarf mistletoe damage rests mainly with manipulation of stand dynamics to minimize spread and intensification. Thorough understanding of dwarf mistletoe/forest stand interactions is therefore crucial to the development and application of controls.

In North America there are some two dozen species of dwarf mistletoes associated with numerous host species growing in a variety of forest and habitat types distributed over different terrains under widely divergent climatic conditions. Detailed treatment of stand dynamics in each of these associations is beyond the scope of this discussion. Rather, I have attempted to highlight some stand and ecological relationships that appear to be general to dwarf mistletoes, to indicate how these relationships provide bases for dwarf mistletoe control, and to suggest where increased information could improve control application. The literature on dwarf mistletoes is voluminous (Scharpf, et al. 1976). Citations were selected to confirm or to illustrate principles, but no attempt was made to cite all papers dealing with the material discussed here.

DAMAGE, IMPACT, AND DWARF MISTLETOE POPULATIONS

Land managers are concerned about dwarf mistletoes because mistletoes can reduce the number, size, quality, or longevity of trees, and such reductions can affect the productivity and value of trees or stands. Unfortunately, a standard terminology to express disease effects has not evolved. Such terms as effect, damage, loss, and impact are often used interchangeably to designate mistletoe-induced changes in trees or stands. It has been suggested that the term impact be restricted to "...the cumulative net effects of a given pest or pest complex on the productivity, usefulness and value of a tree species or forest type with respect to different resource uses and values (timber production, watershed protection, wildlife cover, recreation, etc.) and the management objectives..." (Waters, 1976). By this definition, various types of damage (growth reduction, quality reduction, mortality, etc.) may or may not have impact, depending upon whether such damage reduces the productivity or value of a stand.

Investigators have seldom dealt with impact. Most available data involve various measures of damage either to individual trees or to stands. The following discussion therefore deals mainly with damage, with the recognition that land managers must ultimately convert damage data to impact data and that this conversion is dependent on the amount of damage to individual trees and the numbers and distribution of damaged trees in a stand. These data in turn are dependent on the rates at which mistletoes spread through stands and intensify within trees.

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Generally, the amount of damage is related to the numbers of infections and their distribution within tree crowns (Baranyay 1970; Baranyay and Safranyik 1970; Childs and Wilcox 1966; Dooling 1974; Dooling and Brown 1976; Hawksworth 1961a; Hawksworth and Lusher 1956; Korstian and Long 1922; Pierce 1960; Shea 1963; Shea and Orr 1963; Shea and Belluschi 1965; Smith 1969). A number of systems have been devised to rate intensities of dwarf mistletoe infection (Hawksworth 1977; Dooling, this vol.) and to correlate damage with intensities in individual trees or with general conditions of stands.

Damage on a stand basis is usually estimated by comparing volumes, basal areas, or mortality rates in stands without mistletoe to that in stands with various amounts of mistletoe. While absolute volume, basal area or mortality may differ with different host/mistletoe combinations and with a variety of site and stand factors, the association of increasing loss with increasing mistletoe intensity is well established (Andrews and Daniels 1960; Baranyay 1970; Graham 1960a; Graham and Frazier 1962; Haglund and Dooling 1972; Hawksworth 1958a, 1968a; Hawksworth and Hinds 1964; Hawksworth and Lusher 1956; Lightle 1966; Richardson and van der Kamp 1972; Wagener 1961). In general, stand losses below some critical level of mistletoe intensity are negligible (Baranyay 1970; Baranyay and Safranyik 1970; Dooling 1974; Richardson and van der Kamp 1972; Shea and Orr 1963). This level is a function of numbers of infected trees in a stand, the intensities of infection in these trees, and the amount of damage resulting from different intensities.

Whether damage is expressed as decreased radial, height, or volume growth or as increased mortality, significant damage is seldom observed until at least the lower 1/3-1/2 of a tree crown is heavily infected (Baranyay 1970; Baranyay and Safranyik 1970; Dooling 1974; Dooling and Brown 1976; Hawksworth 1961a; Hawksworth and Lusher 1956; Pierce 1960; Shea 1963; Shea and Orr 1963; Shea and Belluschi 1965; Smith 1969). Light infection throughout the crown or heavy infection in the lower crown usually cause little or no damage, except where stem infections may lead to heartrot (Etheridge 1973), where stem infections occur in seedlings and small saplings (Knutson and Toevs 1972; Roth 1971; Weir 1918), or perhaps where large brooms are produced.

The effects of brooms on host growth has not been investigated thoroughly. Pierce (1960) suggested that the growth of trees with brooms in the lower crown was comparable to trees with healthy crowns of a length equal to the unbroomed portion of infected trees. Hawksworth (1961a), however, showed that growth reduction was greater in broomed trees than in non-broomed trees of the same infection class. Further, Lightle and Hawksworth (1973) illustrate dramatic improvement in host vigor following pruning of brooms from the lower crown. Since the numbers of brooms increase with increasing intensities of infection (Hawskworth 1961a), the amount of damage to trees can be expected to increase with increasing levels of infection.

Rates of increase in dwarf mistletoe population levels undoubtedly are affected by a number of host, stand, and environmental factors. Few data are available on measured rates of increase. Hawksworth (1969) found that the numbers of infections on inoculated digger pines increased from 4 to 240 per tree within 16 years after inoculation, indicating a population doubling rate of about 2.5 years. Doubling rates were estimated to be 1.25 years in lodgepole pine (Muir 1972) and 4 years in hemlock (Richardson and van der Kamp 1972). Scharpf and Parmeter (1976) found that population increases in inoculated red and white firs were highly variable. In two groups of trees, populations doubled within 12-15 years from inoculation; in a third group the population tripled; in a fourth group the population increased 35 times (a doubling rate of about 3 years), and in one group the population scarcely increased. These extreme variations are presently unexplained, but they suggest that the collection of population data in one area may have limited relevance to other areas.

Generalized estimates of population increase rates have been made by rating the mistletoe intensity according to the system of Hawksworth (1977) in stands of different ages or in stands infected for different periods of time. Hawksworth and Hinds (1964) estimated that the average rating (on a 0-6 scale) in lodgepole pine stands increased 0.8-0.9 per decade for the first 4 decades of infection, with increases of 0.6 and 0.3 for the next 2 decades. This indicates an average increase of 1 class each 14 years. Flora (1966) indicated that it takes about 70 years for ponderosa pines to go from a 1.5 to a 5.5 rating, an increase of 1 class each 17.5 years. Wass (1976) suggests that shore pine infection intensities increased by 1 class each 15 years. Myers, et al. (1976) developed an equation for calculating increases in infection intensity for mistletoe in southwestern ponderosa pine. By this equation, rates of increase vary according to time of infection, stand density, and site index.

It is obvious that equations or estimates for population or rating increases can apply only to specified time periods, host/mistletoe combinations, and stand/site conditions. With estimated doubling times of 1.25-4 years, dwarf mistletoe populations would reach impossible numbers within normal rotation periods for most host species. On a stand basis, if infection ratings increased by 1 every 15 years (allowing 10 years for establishment), young infected stands would reach damaging 3-4 levels of infection within 55-70 years, and we would be hard pressed to justify rotations beyond this time. However, for each 5-year increase in the number of years it takes for ratings to increase by 1, the rotation is extended by 30 years (Fig. 1). Whether increase rates are straight-line functions or whether they change with stand age and duration of infection (as the data of Hawksworth and Hinds, 1964, suggest), reduction in the rate of increase may be critical to sound management.

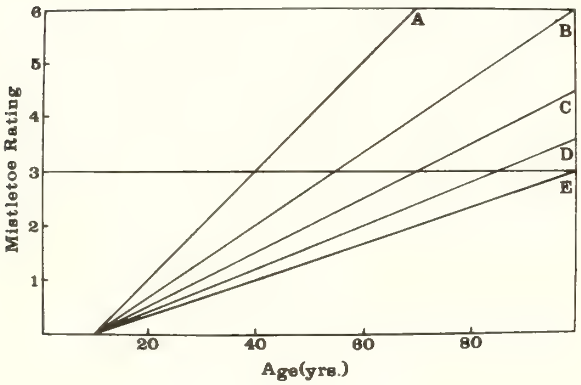

Figure 1--Ages at which stand dwarf mistletoe ratings would reach levels of 3 or more with infection ratings increasing by 1 every 10 yr (A), 15 yr (B), 20 yr (C), 25 yr (D), or 30 yr (E), assuming infection is established at about 10 yr.

Fortunately, rates of dwarf mistletoe spread and increase are subject to a variety of limitations that can be manipulated by land managers or that he can take advantage of. These involve the influences of: (1) site quality and host vigor, (2) stand density, (3) host age, (4) stand structure, and (5) stand composition. These various elements of stand dynamics are inextricably interwoven and difficult to discuss in isolation. For convenience, however, they will be discussed individually.

ELEMENTS OF STAND DYNAMICS AFFECTING SPREAD, INTENSIFICATION, AND DAMAGE

Site Quality and Host Vigor

Reports of the relationship of dwarf mistletoe prevalence, intensity or damage to site quality are difficult to interpret. In ponderosa pine, increased mistletoe has been associated with poor site quality (Daubenmire 1961, 1969; Korstian and Long 1922), with intermediate site quality (Larson et al. 1970), or showed no significant relationship to site (Childs and Edgren 1967; Hawksworth 1961a, 1961b, 1968a). In lodgepole pine, Alexander (1975) reported heavier infection on poor sites, Hawksworth and Graham (1963) found a higher percentage of infected trees in reproduction on good sites, and Hadfield (1977) found no relationship of site quality to percent of trees infected. Baranyay and Safranyik (1970) found greater growth loss on dry than on wet sites. It has been suggested that because mistletoes affect host growth, heavily infected stands may give the appearance of low site quality (Childs and Edgren 1967; Hawksworth 1961a).

Since site quality is measured by tree growth, and growth may be affected by a number of factors (soil type and depth, nutrients, available water, drainage, length of growing season, etc.), it is not surprising that data are difficult to interpret. While site quality per se might have some direct effects on dwarf mistletoe activity, it is likely that fundamental host/stand/parasite interactions affected by site factors are more important in determining mistletoe spread and intensification.

Host vigor, which is in part a reflection of site quality, affects mistletoes in several important ways. Vigorous trees are generally larger, have fuller crowns, greater needle complements, and longer needles than do unthrifty or suppressed trees. It has long been recognized (Weir 1916) and repeatedly confirmed (Childs 1963; Childs and Edgren 1967; Gill 1957; Hawksworth 1961a, 1965; Hawksworth and Graham 1963; Roth 1959; Wicker 1967; Wicker and Shaw 1967) that vigorous, full-crowned trees intercept more seeds and are therefore more liable to infection. It appears well established that for a given level of inoculum, the rate of infection increases with host vigor.

Host vigor also promotes dwarf mistletoe vigor. The endophytic system invades vigorous host tissues more rapidly (Hawskworth 1960a; Scharpf 1962; Parmeter unpubl.), and more robust shoots and larger amounts of seed develop on vigorous hosts (Baranyay and Smith 1972; Childs 1963; Dooling 1974; Hawksworth 1961a; Roth 1953).

It has also been reported that vigorous lodgepole pines are more liable to damage. Statements regarding the effects of host vigor on mistletoe development are not apt to have much significance unless the stand and site characteristics are specified. While a vigorous tree in one stand may be more liable to damage, a similar tree in another stand may be less liable to damage.

Since trees of most species seldom show significant growth losses when mistletoes are confined to the lower crown, factors that affect the rate of vertical spread through tree crowns are important. Alexander (1975) indicated that where the site index exceeded 70, usually only the middle and lower crowns of dominant and codominant lodgepole pines were infected. Below index 70, all crown classes were susceptible to heavy infection throughout the crown. Graham (1967) suggested that vertical spread in ponderosa pine was about 4 inches per year, and Strand (1973) estimated 3 inches per year. Hawksworth (1969) found that vertical spread in digger pines averaged 2 feet per year. Richardson and van der Kamp (1972) estimated vertical spread to be 65 cm (about 2 feet) per year in open grown hemlock and 30 cm (about 1 foot) per year in dense hemlock. Scharpf and Parmeter (1976) found the average vertical spread in red and white firs was about 3 inches per year. Childs (1964), Richardson and van der Kamp (1972), and Scharpf and Parmeter (1976) have suggested that most trees will escape serious damage if the rate of height growth exceeds the rate of vertical spread sufficiently to confine mistletoe to the lower crown and that, in the absence of overstory seed sources, damaging invasion of upper crowns will not occur until host growth slows with age.

The rate of vertical spread is probably governed mainly by crown characteristics. Species with open crowns, such as digger pine, permit rapid vertical spread, whereas species with dense crowns, such as true firs, greatly impede vertical spread. Among trees within a species, crown characteristics can change with host vigor. Vigorous crowns, because of their fullness, will impede vertical spread, even though the rate of population increase in the lower crown may be high. In contrast, unthrifty or suppressed trees, because of thin crowns, may provide less barrier to vertical spread. For each mistletoe/host combination, it may be possible to construct height-growth/vertical-spread curves that will allow prediction of probable damage for any set of vigor and site conditions (Fig. 2).

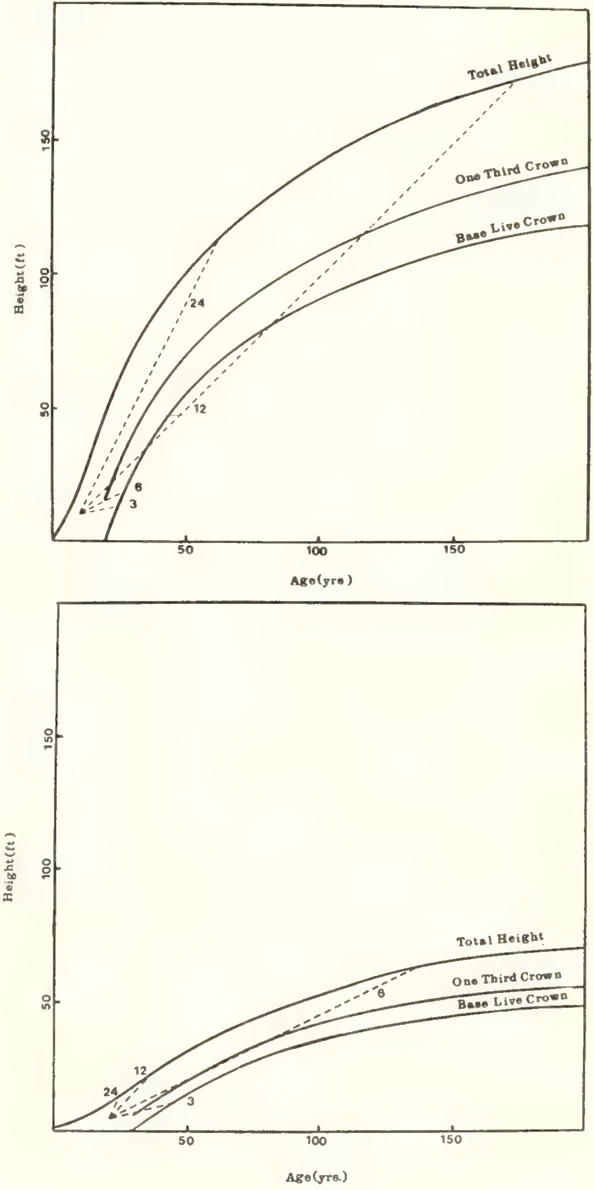

Figure 2--Hypothetical relationship of vertical spread rates of 3, 6, 12, or 24 inches per year to position of dwarf mistletoe in crowns of trees at different ages on high and low sites. Infection of young trees is estimated to occur slightly earlier on high sites.

In addition to rates of population buildup within crowns, site and vigor might also affect rate of tree-to-tree spread through a stand. Trees of low vigor on poor sites have thin crowns and might therefore provide less "screening" for lateral spread. Such effects, if any, would likely be small in comparison to the effects of stand density, structure, and composition.

Stand Density

Stand density can affect spread and intensification either directly or through changes in host vigor and growth. In general, mistletoes spread more rapidly in open stands than in dense stands (Hawksworth 1958a, 1961a). Hawksworth (1961a) found that average spread in open stands of ponderosa pine reproduction was 1.5 times as fast (1.7 feet/year) in open stands as in dense stands (1.2 feet/year). Data on spread in lodgepole pine were similar (Hawskworth 1958a) but spread rates were slightly less (average 1.2 feet/year vs. 1.5 feet/year). Density may affect spread in several ways. Beyond some critical distance that varies with tree size and mistletoe species, the chances of seed shooting from one tree to another decrease until trees are so far apart that ballistic spread is very unlikely (Fig. 3). As spacing decreases, the likelihood of seed reaching adjacent trees increases until densities are sufficiently high that trees interfere with spread by "screening" out seeds, thus "protecting" the trees beyond. Where densities are sufficiently high as to reduce host growth and vigor, seed production may be reduced, thus decreasing the opportunities for spread. The generalized relationship of density to spread presented by Hawksworth (1961a) undoubtedly can be applied to most mistletoe/host combinations, but the curve would have to be adjusted according to species and to the sizes of trees involved.

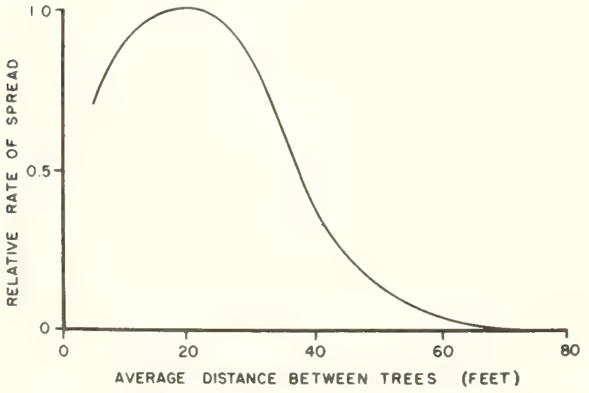

Figure 3--Rate of dwarf mistletoe spread in relation to stand density (after Hawksworth 1961a).

The rate of mistletoe increase and subsequent host damage is also related to stand density, but the relationship is not entirely clear. Some workers have reported an inverse relationship of density to prevalence or damage (Graham 1960b; Richardson and van der Kamp 1972; Williams et al. 1972). Williams et al. (1972) suggested, however, that infection in limber pine was directly related to density. Since density relationships are relative and may vary according to a variety of site and stand factors, generalizations are feasible only within specific contexts; e.g., similar densities on high and low sites may not have similar effects on dwarf mistletoes.

Density can affect host vigor, as has already been discussed. Where the relationship of height growth to vertical spread of mistletoe is changed by crowding and suppression, the rate of crown involvement might be expected to change, but the nature of the change may depend on specific densities. Childs (1964) has discussed in some detail the relationship of crown closure to mistletoe population increase and vertical spread. Baranyay and Smith (1972), Childs (1963), Richardson and van der Kamp (1972) and Scharpf and Parmeter (1976) have also suggested that crown closure and subsequent "pruning" of lower branches may stabilize or reduce population increases in tree crowns. If the rate of crown closure and branch pruning is greater than the rate of vertical spread, populations of dwarf mistletoes might virtually disappear from trees not exposed to overstory seed sources (Fig. 2).

The above observations suggest that for each site/host/mistletoe combination there is an optimum density that promotes good height growth and rapid crown closure to minimize population buildup and vertical spread of mistletoe. At densities above optimum, crown thinning and reduced height growth might lead to increased vertical spread, or with densities below optimum, increased branch longevity, increased mistletoe inoculum, and increased opportunities for "stepwise" vertical spread between trees might also lead to increase damage. The relation of site and density to vertical spread and population buildup warrants research emphasis.

Stand Age and Size Structure

Trees of any age or size are susceptible to dwarf mistletoe infections. Seedlings one-year-old or less are readily infected under greenhouse conditions (Knutson and Toevs 1972; Knutson 1974), and infection of trees 2.5 inches tall have been observed in nature (Hawksworth and Graham 1963). Infection of very young or very small trees is, however, relatively rare. Data from many sources indicate that numbers of trees infected, intensity of infection, and degree of damage consistently increase with the age of trees or stands and, in the case of reproduction exposed to overstory seed sources, with size of trees (Baranyay 1970; Childs 1963; Graham 1960a, 1964; Hadfield 1977; Hawksworth 1958a, 1961a; Hawksworth and Graham 1963; Hawksworth and Hinds 1964; Muir 1972; Scharpf 1969a; Stewart 1976). The escape of or reduced infection in young trees involves the relatively small target area, the short duration of exposure to inoculum, and the short period for inoculum production and spread within crowns. Loss of seeds under snow may also reduce infection of small trees (Wicker 1967).

Because young trees tend to escape infection, reproduction following opening of infested stands by logging, fire, insects or other agencies is ordinarily lightly infected until it reaches some critical age or size. Jones (1974), Shea and Stewart (1972), and Scharpf (1969a) have provided guidelines for timing of overstory removal. If overstory sources of mistletoe seed are removed, subsequent buildup and damage in the released stand depend upon the site and density factors already discussed and upon silvicultural manipulation of the young stand, as will be discussed in later sections of this symposium.

At the opposite end of stand development, all trees eventually cease appreciable height growth. In such trees, vertical spread can be expected to involve the entire crown, and the intensity of infection can be expected to increase because of the long duration of exposure to inoculum. Mortality rates are apt to be high in old stands in which heavy infection levels have been reached.

Roth (1953) suggested that less mistletoe seed is produced in old, declining trees than in young trees. Although seed production may be reduced, appreciable numbers of seeds have been trapped under old, heavily infected and broomed trees (Parmeter and Scharpf 1972). It is probably safest to consider all such trees as potential sources of inoculum.

Perhaps the most firmly established of all stand influences on dwarf mistletoes is that of stand structure (Gill and Hawksworth 1954; Graham and Frazier 1962; Graham 1959a; Hawksworth 1961a; Kimmey and Graham 1960; Kuiyt 1955; Roth 1953; Scharpf and Hawksworth 1968, Shea 1963; Shea and Stewart 1972; and many others). In stands comprised of susceptible trees of different sizes, the crowns of smaller trees are continually exposed to inoculum from larger trees. Under these circumstances, the upper crowns of understory trees can rarely remain free of increasing mistletoe populations, and reductions in growth with further increase in mistletoe is almost certain. The impact of mistletoe in such stands can render them virtually non-productive.

The rate of spread through two-storied or multistoried stands is more rapid than through single-storied stands. Small trees provide little "screening" of mistletoe seeds, therefore tall seed sources provide for greater unimpeded seed trajectories. Hawksworth (1961a) calculated trajectories for mistletoe seeds discharged at different angles (Fig. 4). From these calculations, it is evident that, in the example shown, a nearby tree less than 40 feet tall would not impede flight from the 50 foot seed source at most discharge angles above the horizontal. A nearby 60 foot tree would, however, intercept seeds and markedly reduce the distance of flight.

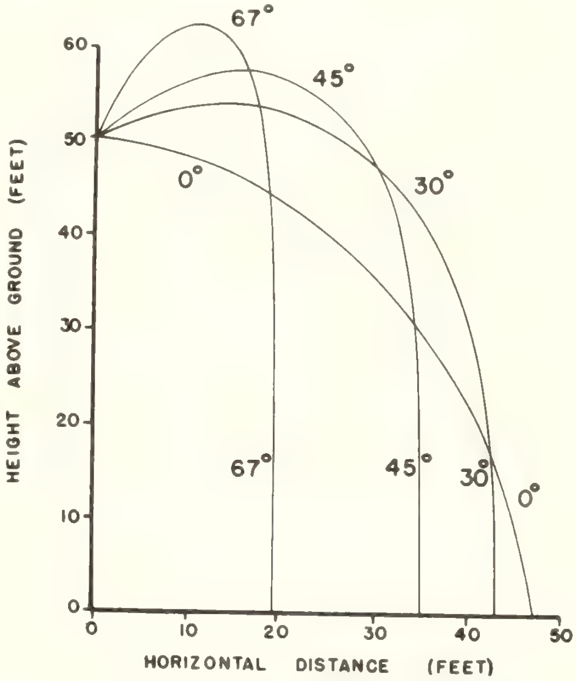

Figure 4--Calculated trajectories of dwarf mistletoe seeds expelled at four vertical angles from a point 50 feet above ground level (after Hawksworth 1961a).

Average distances of maximum spread, based on seed trapping or on infection of reproduction, range from about 40-60 feet in southwestern ponderosa pine (Gill 1954; Gill and Hawksworth 1954; Hawksworth 1961a, 1961b), 25-60 feet in lodgepole pine (Gill and Hawksworth 1964; Hawksworth and Graham 1963; Hawksworth

1973; Muir 1970), and 15-50 feet for western hemlock (Shea and Stewart 1972; Smith 1973). These data correspond well with trajectories calculated by Hawksworth.

Wind may, however, increase the distance of spread. Seed from tall overstory ponderosa or Jeffrey pines can be deposited on smaller trees over distances of 100 feet or more (Roth 1953; Scharpf and Parmeter 1967, 1971; Parmeter and Scharpf 1972) and could infect nearly an acre of reproduction if so dispersed in all directions. Muir found that spread from isolated overstory trees was greater (avg. 45 feet) than from stand margins (avg. 28 feet). The above data indicate that greatest distances of spread are associated with tall, isolated overstory trees exposed to wind. Least distances of spread are associated with relatively even-aged stands.

Stand Composition

The geographic ranges of many species of dwarf mistletoes overlap (Hawksworth and Wiens 1972); however, the occurrence of two species of mistletoe in the same place is not common. While a variety of "crossovers" among host species have been observed (Gill and Hawksworth 1961; Hawksworth 1974; Hawksworth and Wiens 1972; Muir 1973; Smith 1974), in general, one or more species in a mixed stand will be free of mistletoe (Kjuit 1955).

The effects of stand composition on any one host species have not been well documented. In some areas, mistletoe is more frequent in stands where the host species predominates (Graham 1964). In other areas, mistletoe is as abundant or more so in stands where the host species is a lesser component (Acciavatti and Weiss 1974; Graham 1959b, 1960b). In stands undergoing conversion, mistletoe damage is often reduced (Baranyay and Smith 1972; Jones 1974; Hawksworth 1973), and selective pressure on one host may promote stand conversion (Parmeter and Scharpf 1963).

While quantitative data are limited, it can be argued a priori that mistletoe impact will be reduced in mixed stands because a percentage of the trees will not be damaged. Spread through mixed stands may also be reduced if nonsusceptible trees are sufficiently large and sufficiently numerous as to impede flight of mistletoe seeds between susceptible trees. Manipulation of stand composition to reduce damage has been recommended (Baranyay and Smith 1972; Jones 1974; Kimmey 1957; Kimmey and Graham 1960; Parmeter and Scharpf 1963; Scharpf 1964, 1969a; Schwandt 1977).

Stand History

Discussion of dwarf mistletoes and stand dynamics would not be complete without consideration of special events in the history of stand development that affect the characteristics of stands and the incidence of dwarf mistletoes. Chief among these are logging, fire, forest succession, insect activity, and possibly the evolution of resistance mechanisms. These past events probably have had major influences on the mistletoe situations we observe today.

Logging and other stand manipulations will be discussed in following sections of this symposium and will not be dealt with in detail here. Obviously, past cutting practices that have modified vigor, density, age, structure, and composition of stands have influenced mistletoe activity as previously indicated. In a sense we have inherited many of our mistletoe problems from past forest practices. High-grading, selective cutting, and preferential removal of certain species have left many stands open, multistoried, reduced in species complexity, and in a condition to favor rapid buildup and damage by mistletoe. Conversely, extensive clearcutting in some timber types has resulted in large areas of essentially mistletoe-free second growth.

Along with logging, fire has undoubtedly had a major influence on present mistletoe conditions in many areas. The relationship of fire to mistletoe activity has been thoroughly discussed in the excellent reviews of Alexander and Hawksworth (1975) and Wicker and Leaphart (1976) and will be discussed by Muraro in a later section of this symposium. Fires may have positive or negative effects on dwarf mistletoes, depending on the extent and intensity of the burn and on the characteristics of the stand and the terrain. Where large areas of forest have been completely destroyed by intense wildfire, the replacement stand will be mistletoe free except at the margins. Since dwarf mistletoes reinvade such new stands at an average of only 1-2 feet per year following initial infection from the margins (Hawksworth 1958a, 1960b, 1961a; Shea and Stewart 1972; Wagener 1965), large areas of replacement stands remain mistletoe free.

Owing to patchy fuel accumulations, rock outcrops, and other irregularities, even large fires often leave groups or individual live trees within burned areas. When infected, these can serve as sources of inoculum to reinfest the replacement stand. In some regions, the prevalence of dwarf mistletoes is markedly associated with areas where large, complete burns are rare because of terrain or fuel conditions (Baranyay 1970).

Available evidence suggests that frequent low-intensity ground fires were characteristic of many forest types (Biswell 1967; Weaver 1974). Because heavy dwarf mistletoe infection leads to accumulation of dead trees, witches' brooms, resinous stems and branches, and other fuels, low intensity fires may flare up and consume most of the trees in localized infection centers. In addition, heavy brooming provides concentrated fuel for "torching" and destruction of infected trees, where normal tree crowns are too open to carry fire up the tree. Low intensity fires may also kill infected lower branches, thus reducing mistletoe populations in lower crowns (Roth 1974). These fire effects have probably reduced mistletoes in many areas, but not all fire effects have been beneficial.

In the long view, fires have also served to perpetuate seral fire types in which dwarf mistletoes may be a perpetual problem. In addition, owing to accumulation of fuels in stands with mistletoe levels sufficient to apply selection pressures for resistance, locally intense fires may have greatly reduced opportunities for the evolution of resistance, since any resistant trees within such stands would be consumed along with infected trees (Roth 1966).

Resistance to dwarf mistletoes is infrequently observed and poorly understood. Some trees within stands are essentially free of mistletoe, even when exposed to abundant inoculum (Hawksworth 1961a, Roth 1953, 1971; Wagener 1965). In other cases, stands over large areas may show differing susceptibilities. Hawksworth (1961b) found that inoculation of trees in infested stands produced 10 times the rate of infection obtained from inoculations in uninfested stands, apparently because of differences in the survival of germinated seed. Infection of ponderosa pine by A. americanum is uncommon in stands infested by A. vaginatum and vice versa (Hawksworth 1968b). Scharpf and Parmeter (1967) provided limited evidence that Jeffrey pines from high elevation seed sources were more susceptible than trees from low elevation sources. Smith and Wass (1976) found that A. tsugensis includes forms that preferentially attack shore pine in some areas and hemlock in others. Hawksworth and Wiens (1972) discussed the "exclusion principle", a frequently observed phenomenon in which other species of mistletoes seldom infect trees in stands infested by a principal dwarf mistletoe of the host.

While genetic interactions among hosts and parasites undoubtedly account for some of the above observations and some bases for resistance have been suggested (Roth 1966; Smith 1974), environmental limitations and evolution of ecotypes might also account for different host/parasite interactions in different stands. These phenomena deserve further investigation, since prediction of mistletoe damage in different stands may rest with understanding of the bases for differing host/parasite interactions.

Forest succession has also influenced the present distribution and intensity of dwarf mistletoes. As has been pointed out by Hawksworth (1973), mistletoe damage is often reduced when stands of seral species are replaced by "climax" species. It can be argued that in stands where succession from one species to another is possible, dwarf mistletoe will apply pressure against the susceptible host, thus hastening stand succession (Parmeter and Scharpf 1963). However, if mistletoe species attacking the "climax" species are present in stands, reduction of mistletoe damage by succession may be only temporary.

Wass (1976) indicated that hemlock mistletoe on shore pine is mainly a problem where shore pine tends to be climax. In California, it appears that heavy mistletoe damage is often associated with such timber types as eastside Jeffrey pine, upper elevation red fir, and poor-site lodgepole pine in which the host species are self perpetuating and opportunities for succession to other species or to mixtures are minimal. Perpetuation of "climax" types may eventually lead to heavy mistletoe damage because such types tend, in the absence of catastrophic removal, to develop uneven-aged structures, a condition favoring dwarf mistletoe intensification.

It is difficult to reconstruct past successional changes that have affected present mistletoe conditions. It seems safe to assume, however, that frequent changes in timber type resulting from the interplay of catastrophe and succession have helped to reduce mistletoe incidence. And conversely, perpetuation of the same type, either seral fire types or "climax" types has tended to increase mistletoe damage. Knowledge of such trends can aid land managers in long-range planning.

While logging, fire, and succession are probably the main factors that have shaped the character of stands and the distribution of mistletoes within stands, other events have likely had significant influence. Epidemic insect activity can change the composition and structure of forest stands (Schmid and Hinds 1974). Few data are available to assess possible effects of insect activity on dwarf mistletoe populations, and both plus and minus effects can be postulated. Infected trees are often attacked by bark beetles (Hawksworth 1973), and each killed, infected tree represents a temporary reduction in inoculum. However, random killing of individual trees may lead to open, uneven-aged stands in which mistletoes are ultimately more damaging. Extensive killing, as can result from repeated defoliation of lodgepole pine by needle miners (Koerber and Struble 1971), might have effects similar to fire in that replacement stands would tend to be even-aged and surviving overstory trees would provide inoculum for infection of reproduction.

Dwarf mistletoes may also influence insect activity. Trees weakened by dwarf mistletoes are often susceptible to bark beetle attack (Hawksworth 1973; Miller and Keen 1960; Struble 1965), although heavily infected trees may provide poor substrate for brood development (Roe and Amman 1970). Details of possible relationships between dwarf mistletoes and population dynamics of destructive forest insects are poorly understood and should provide a fruitful area for further study.

OTHER ECOLOGICAL INFLUENCES

Available evidence suggests that a variety of factors other than stand dynamics per se affect the occurrence and intensity of dwarf mistletoe populations. Many of these factors are not well understood and evidence for their influences is often circumstantial. Mistletoes are higher plants and we can expect that they are subject to many of the same environmental limitations that govern the distribution of other higher plants. Detailed discussion of these ecological factors is beyond the scope of this paper, but mention should be made of their existence and possible implications in land management.

The distribution of dwarf mistletoes is not continuous over the ranges of their host species. These discontinuities have been discussed by a number of workers (Baranyay and Smith 1972; Baranyay 1970; Hawksworth and Wiens 1972; Smith and Baranyay 1970; Wicker 1974b). They include the absence of mistletoes over large geographic areas (Hawksworth and Wiens 1972); the absence from certain habitat types (Acciavatti and Weiss 1974; Hadfield 1977; Hawksworth 1973; Hawksworth and Wiens 1972), and absence or reduced activity in relation to slope, aspect, and other topographic features (Andrews and Daniels 1960; Baranyay 1970; Gill 1957; Gill and Hawksworth 1961, 1964; Hawksworth 1958b, 1961a, 1968a; Larson et al. 1970; Roth 1954; Williams et al. 1972).

The absence of dwarf mistletoes on some hosts over major portions of the host range may involve large scale shifts in ranges associated with advance and retreat of ice sheets during glacial epochs (Hawksworth and Wiens 1972). Other large-scale discontinuities may be due to geographical barriers or discontinuities in the distribution of host species (Wicker 1974b). On a smaller scale, absence of mistletoe can involve such catastrophes as volcanic devastation (Hawskworth 1960b).

Environmental limitations may also be responsible for some of the observed patterns of dwarf mistletoe distribution. Seed survival, germination, and radicle development are sensitive to both high and low temperature extremes (Beckman and Roth 1968; Knutson 1971; Scharpf 1969b, Wicker 1974a). Gill (1957) recognized that the upper elevational limit of _A. americanum_ in the Rocky Mountains coincides with the 30 F mean annual isotherm. Baranyay and Smith (1974) showed that freezing temperatures before or during seed dispersal permanently damaged fruits and greatly reduced seed discharge of _A. americanum_ and _A. tsugense_.

In some regions, mistletoes may be restricted by inadequate moisture during the period of germination and infection (Bonga 1969, Hawksworth 1967). Moisture is required for seed germination, and unsuitable moisture conditions may reduce viability, germination, or survival (Bonga 1969; Knutson 1971; Wicker 1974a).

Our present state of knowledge about requirements and limitations is inadequate to permit firm correlation of distribution patterns with environmental limitations in most cases, but it seems reasonably certain that such limitations exist. Future studies may help to distinguish between areas that are mistletoe free because mistletoes haven't successfully spread into them and areas that are mistletoe free because mistletoes can't successfully spread into them. In either case, today's land managers must deal with mistletoes where they are, and prudent land managers will take steps to minimize the possibility of their spread or introduction into areas presently free of mistletoes on important hosts.

CONCLUSIONS

Mistletoe damage and impact in forest stands are mainly functions of the numbers of infected trees and the distribution and numbers of infections within tree crowns. These parameters are in turn functions of the rates at which mistletoes spread through stands, the rates at which they spread vertically within crowns, and the rates at which populations increase. These rates are governed in large part by stand characteristics that can be manipulated by land managers.

Basic principles of tree/stand/mistletoe interactions are well established and provide broad guidelines for stand management. Many refinements of our information base will be necessary to develop precision in the management of the many timber types and host/mistletoe combinations under different geographic, topographic, climatic, and site conditions. Ultimately, predictive models of varying precision, as have been explored by Myers, et al. (1976), Strand and Roth (1976), and Edminster (this vol.), should become available to managers. We need not wait for such models, however. The broad principles already developed can and should be applied to the management of stands in which dwarf mistletoes are an actual or potential problem. Ideally, as these principles are applied, post-treatment research and monitoring on a long-term basis will: (1) provide needed refinement of our data base, (2) confirm or dismiss presently uncertain but suspected relationships, and (3) lead to the development of new concepts and approaches to the control of dwarf mistletoe impact.

LITERATURE CITED

Acciavatti, R. E., and M. J. Weiss.
1974. Evaluation of dwarf mistletoe on Engelmann spruce, Fort Apache Indian Reservation, Arizona. Plant Dis. Rep. 58:34-35.

Alexander, R. R.
1975. Partial cutting in old-growth lodgepole pine. USDA For. Serv. Res. Pap. RM-136. 17 p.

Alexander, M. E. and F. G. Hawksworth.
1975. Wildlands fires and dwarf mistletoes: a literature review of ecology and prescribed burning. USDA For. Serv. Gen. Tech. Rep. RM-14. 12 p.

Andrews, S. R. and J. P. Daniels.
1960. A survey of dwarfmistletoes in Arizona and New Mexico. USDA For. Serv., Rocky Mtn. For. Range Exp. Stn. Pap. 49. 17 p.

Baranyay, J. A.
1970. Lodgepole pine dwarf mistletoe in Alberta. Can. For. Serv. Publ. 1286. 22 p.

Baranyay, J. A., and L. Safranyik.
1970. Effect of dwarf mistletoe on growth and mortality of lodgepole pine in Alberta. Can. For. Serv. Publ. 1285. 19 p.

Baranyay, J. A., and R. B. Smith
1972. Dwarf mistletoes in British Columbia and recommendations for their control. Can. For. Serv. BC-X-72. 18 p.

Baranyay, J. A., and R. B. Smith
1974. Low temperature damage to dwarf mistletoe fruit. Can. J. For. Res. 4:361-365.

Beckman, K. M., and L. F. Roth
1968. The influence of temperature on longevity and germination of seed of western dwarf mistletoe. Phytopathology 58:147-150.

Biswell, H. H.
1967. Forest fire in perspective. Proc. Tall Timbers Fire Ecology Conf.:43-64.

Bonga, J. M.
1969. Growth potential of seeds and site requirements of eastern dwarf mistletoe. Can. Dep. Fish and For., Bi-monthly Res. Notes 25(2):10-11.

Childs, T. W.
1963. Dwarfmistletoe control opportunities in ponderosa pine reproduction. USDA For. Serv., Pac. Northw. For. Range Exp. Stn. Ofc. Rep. 20 p.

Childs, T. W., and J. W. Edgren
1967. Dwarfmistletoe effects on ponderosa pine growth and trunk form. For. Sci. 13:167-174.

Childs, T. W., and E. R. Wilcox
1966. Dwarfmistletoe effects in mature ponderosa pine forests in south-central Oregon. J. For. 64:246-250.

Daubenmire, R.
1961. Vegetative indicators of rate of height growth in ponderosa pine. For. Sci. 7:24-34.

Daubenmire, R.
1969. Ecological plant geography of the Pacific Northwest. Madroño 20:111-128.

Dooling, O. J.
1974. Dwarf mistletoe control--why and what?

USDA For. Serv. - Northern Reg. Rep. 74-16. 11 p.

Dooling, O. J., and D. H. Brown
1976. Guidelines for dwarf mistletoe control in lodgepole pine in the northern and central Rocky Mountains. USDA For. Serv., Northern Reg., For. Environ. Prof. Rep. 76-14. 10 p.

Etheridge, D. E.
1973. Wound parasites causing tree decay in British Columbia. Can. Dep. Environ. For. Serv., Pac. For. Res. Cent. For. Pest Leafl. 62. 15 p.

Flora, D. F.
1966. A method of forecasting returns from ponderosa pine dwarfmistletoe control. USDA For. Serv. Res. Pap. PNW-32. 17 p.

Gill, L. S.
1954. Dwarfmistletoe of ponderosa pine in the Southwest. USDA For. Serv., Rocky Mtn. For. Range Exp. Stn., Stn. Paper 14. 9 p.

Gill, L. S.
1957. Dwarfmistletoe of lodgepole pine. USDA For. Serv., For. Pest Leafl. 18. 7 p.

Gill, L. S., and F. G. Hawksworth
1954. Dwarfmistletoe control in southwestern ponderosa pine forests under management. J. Forestry 52:347-353.

Gill, L. S. and F. G. Hawksworth
1961. The mistletoes, a literature review. USDA Tech. Bull. 1242. 87 p.

Gill, L. S., and F. G. Hawksworth
1964. Dwarfmistletoe of lodgepole pine. USDA For. Serv. For. Pest Leafl. 18. 7 p.

Graham, D. P.
1959a. Dwarfmistletoe survey in Kootenai National Forest. USDA For. Serv. Interm. For. Range Exp. Stn. Res. Note 67. 5 p.

Graham, D. P.
1959b. Dwarfmistletoe survey in Coeur D' Alene National Forest. USDA For. Serv., Interm. For. Range Exp. Stn. Res. Note 68. 5 p.

Graham, D. P.
1960a. Dwarfmistletoe survey in Nezperce National Forest. USDA For. Serv., Interm. For. Range Exp. Stn. Res. Note 75. 7 p.

Graham, D. P.
1960b. Dwarfmistletoe survey in Kaniksu National Forest. USDA For. Serv., Interm. For. Range Exp. Stn. Res. Note 74. 6 p.

Graham, D. P.
1964. Dwarfmistletoe survey in western Montana. USDA For. Serv. Res. Note INT-14. 7 p.

Graham, D. P.
1967. A training aid on dwarf mistletoe and its control. USDA For. Serv., Pac. Northw. Reg., Portland, Oregon. 40 p.

Graham, D. P., and W. E. Frazier
1962. Dwarfmistletoe survey in northeastern Washington. USDA For. Serv., Interm. For. Range Exp. Stn. Res. Note 103. 8 p.

Hadfield, J. S.
1977. A disease survey of lodgepole pine stands in Oregon and Washington. USDA For. Serv., Pac. Northw. Region, For. Insect Disease Management. 13 p.

Haglund, S. A., and O. J. Dooling
1972. Observations on the impact of dwarf mistletoe on Douglas-fir in western Montana. USDA For. Serv., Northwest Reg. Rep. D-72-1.

Hawksworth, F. G.
1958a. Rate of spread and intensification of dwarfmistletoe in young lodgepole pine stands. J. For. 56:404-407.

Hawksworth, F. G.
1958b. Survey of lodgepole pine dwarfmistletoe on the Roosevelt, Medicine Bow, and Bighorn National Forests. USDA For. Serv., Rocky Mtn. For. Range Exp. Stn. Pap. 35. 13 p.

Hawksworth, F. G.
1960a. Growth rate of dwarfmistletoe infections in relation to the crown class of the host. USDA For. Serv. Rocky Mtn. For. Range Exp. Stn. Res. Note 41. 4 p.

Hawksworth, F. G.
1960b. Distribution of ponderosa pine dwarfmistletoe in the vicinity of an Arizona volcano. Ecology 41:799-800.

Hawksworth, F. G.
1961a. Dwarfmistletoe of ponderosa pine in the Southwest. USDA For. Serv. Tech. Bull. 1246. 112 p.

Hawksworth, F. G.
1961b. Dwarfmistletoes of ponderosa pine. Pages 1537-1541 in Recent Advances in Botany. Univ. Toronto Press, Toronto, Can.

Hawksworth, F. G.
1965. Life tables for two species of dwarf mistletoe. 1. Seed dispersal, intercep-

tion and movement. For. Sci. 11:142-151.

Hawksworth, F. G.
1967. Distribution of ponderosa pine dwarf mistletoe on the south rim of Grand Canyon, Arizona. Plant Dis. Rep. 12:1049-1051.

Hawksworth, F. G.
1968a. Ponderosa pine dwarf mistletoe in relation to topography and soils on the Manitou Experimental Forest, Colorado. USDA For. Serv. Res. Note RM-107. 4 p.

Hawksworth, F. G.
1968b. Lodgepole pine dwarf mistletoe on ponderosa pine. Plant Dis. Rep. 52:125-127.

Hawksworth, F. G.
1969. Rapid intensification and upward spread of dwarf mistletoe in inoculated digger pines. Plant Dis. Rep. 53:615-616.

Hawksworth, F. G.
1973. Dwarf mistletoe and its role in lodgepole pine ecosystems. Pages 342-358 In Proc. Manage. Lodgepole Pine Ecosystems Symp. D. M. Baumgartner, ed. Wash. State Univ., Pullman.

Hawksworth, F. G.
1974. Mistletoes on introduced trees of the world. USDA For. Serv. Agric. Handb. 469. 49 p.

Hawksworth, F. G.
1977. The 6-class dwarf mistletoe rating system. USDA For. Serv. Gen. Tech. Rep. RM-48. 7 p.

Hawksworth, F. G., and D. P. Graham
1963. Spread and intensification of dwarfmistletoe in lodgepole pine reproduction. J. For. 61:587-591.

Hawksworth, F. G. and T. E. Hinds
1964. Effects of dwarfmistletoe on immature lodgepole pine stands in Colorado. J. For. 54:384-390.

Hawksworth, F. G., and A. A. Lusher.
1956. Dwarfmistletoe survey and control on the Mescalero Apache Reservation, New Mexico. J. For. 54:384-390.

Hawksworth, F. G., and D. Wiens
1972. Biology and classification of dwarf mistletoes (Arceuthobium). USDA For. Serv. Agric. Handb. 401. 234 p.

Jones, J. R.
1974. Silviculture of southwestern mixed conifers and aspen: the status of our knowledge. USDA For. Serv. Res. Pap. RM-122. 44 p.

Kimmey, J. W.
1957. Dwarfmistletoes of California and their control. USDA Calif. For. Range Exp. Stn. Tech. Pap. 19. 12 p.

Kimmey, J. W., and D. P. Graham
1960. Dwarfmistletoes of the Intermountain and northern Rocky Mountain regions and suggestions for control. USDA For. Serv., Interm. For. Range Exp. Stn. Res. Pap. 60. 19 p.

Knutson, D. M.
1971. Dwarf mistletoe seed storage best at low temperature and high relative humidity. USDA For. Serv. Res. Note PNW-145. 8 p.

Knutson, D. M.
1974. Infection techniques and seedling response to dwarf mistletoe. Plant Dis. Rep. 58:235-238.

Knutson, D. M., and W. J. Toevs
1972. Dwarf mistletoe reduces root growth of ponderosa pine seedlings. For. Sci. 18:323-324.

Koerber, T. W., and G. R. Struble
1971. Lodgepole needle miner. USDA For. Serv., For. Pest Leafl. 22. 8 p.

Korstian, C. F., and W. H. Long
1922. The western yellow pine mistletoe. U.S. Dep. Agric., Agric. Bull. 1112. 35 p.

Kuijt, J.
1955. Dwarf mistletoes. Botan. Rev. 21:569-620.

Larson, F. R., P. F. Folliott, and W. P. Clary
1970. Distribution of dwarf mistletoe in ponderosa pine stands on the Beaver Creek watershed, Arizona. USDA For. Serv. Res. Note RM-175. 4 p.

Lightle, P. C.
1966. Dwarf mistletoe reduces basal area growth in ponderosa pine in the Southwest. (Abstr.) Phytopathology 56:886-887.

Lightle, P. C., and F. G. Hawksworth
1973. Control of dwarf mistletoe in a heavily used ponderosa pine recreation forest: Grand Canyon, Arizona. USDA For. Serv. Res. Pap. RM-106. 22 p.

Miller, J. M., and F. P. Keen
1960. Biology and control of the western

pine beetle. USDA Misc. Publ. 800. 381 p.

Muir, J. A.
1970. Dwarf mistletoe spread in young lodgepole pine stands in relation to density of infection sources. Dep. Fish For. Bi-mon. Res. Notes 26:49.

Muir, J. A.
1972. Increase of dwarf mistletoe infections on young lodgepole pines. Can. J. For. Res. 2:413-416.

Muir, J. A.
1973. Lodgepole pine dwarf mistletoe on Douglas fir in Alberta. Can. For. Serv. Bi-mon. Res. Notes 29:25-26.

Myers, C. A., C. B. Edminster, and F. G. Hawksworth
1976. SWYLD2: Yield tables for even-aged and two storied stands of Southwestern ponderosa pine, including effects of dwarf mistletoes. USDA For. Serv. Res. Pap. RM-163. 25 p.

Parmeter, J. R., Jr., and R. F. Scharpf
1963. Dwarf mistletoe on red fir and white fir in California. J. For. 61:371-374.

Parmeter, J. R., Jr., and R. F. Scharpf
1972. Spread of dwarf mistletoe from discrete seed sources into young stands of ponderosa and Jeffrey pines. USDA For. Serv. Res. Note PSW-269. 5 p.

Pierce, W. R.
1960. Dwarf mistletoe and its effect upon the larch and Douglas fir of western Montana. Mont. St. Univ. Sch. For. Bull. 10. 38 p.

Richardson, K. S., and B. J. van der Kamp
1972. The rate of upward advance and intensification of dwarf mistletoe on immature western hemlock. Can. J. For. Res. 2:313-316.

Roe, A. L., and G. D. Amman
1970. The mountain pine beetle in lodgepole pine forests. USDA For. Serv. Interm. For. Range Exp. Stn. Res. Pap. INT-71. 23 p.

Roth, L. F.
1953. Pine dwarf mistletoe on the Pringle Falls Experimental Forest. USDA For. Serv., Pac. Northw. For. Range Exp. Stn. Note 91. 3 p.

Roth, L. F.
1954. Distribution, spread and intensity of dwarf mistletoe on ponderosa pine. Phytopathology 44:504.

Roth, L. F.
1959. Natural emplacement of dwarf mistletoe seed on ponderosa pine. For. Sci. 5: 365-369.

Roth, L. F.
1966. Foliar habit of ponderosa pine as a heritable basis for resistance to dwarf mistletoe. Pages 221-228 in Breeding Pest-Resistant Trees (H. D. Gerold, R. E. McDermott, E. J. Schreiner, and J. A. Winieski, eds.). Pergamon Press, New York. 505 p.

Roth, L. F.
1971. Dwarf mistletoe damage to small ponderosa pines. For. Sci. 17:373-380.

Roth, L. F.
1974. Juvenile susceptibility of ponderosa pine to dwarf mistletoe. Phytopathology 64:689-692.

Scharpf, R. F.
1962. Growth rate of the endophytic system of the dwarf mistletoe on digger pine. USDA For. Serv., PSW Res. Note 193. 5 p.

Scharpf, R. F.
1964. Dwarf mistletoe on true firs in California. USDA For. Pest Leafl. 89. 7 p.

Scharpf, R. F.
1969a. Dwarf misteltoe on red fir, infection and control in understory stands. USDA For. Serv. Res. Pap. PSW-50. 8 p.

Scharpf, R. F.
1969b. Temperature affects penetration and infection of pines by dwarf mistletoes. For. Sci. 15:149-151.

Scharpf, R. F. and F. G. Hawksworth
1968. Dwarf mistletoe on sugar pine. USDA For. Serv., For. Pest Leafl. 113. 4 p.

Scharpf, R. F., F. G. Hawksworth, and B. J. Erickson
1976. Mistletoe literature of the world: a user's guide to a FAMULUS retrieval system. USDA For. Serv. Gen. Tech. Rep. RM-30. 5 p.

Scharpf, R. F., and J. R. Parmeter
1967. Spread of dwarfmistletoe into Jeffrey pine plantation. USDA For. Serv. Res. Note PSW-141. 6 p.

Scharpf, R. F. and J. R. Parmeter, Jr.
1971. Seed production and dispersal by dwarf mistletoe in overstory Jeffrey pines

in California. USDA For. Serv. Res. Note PSW-247. 5 p.

Scharpf, R. F., and J. R. Parmeter, Jr.
1976. Population buildup and vertical spread of dwarf mistletoe on young red and white firs in California. USDA For. Serv. Res. Pap. PSW-122. 9 p.

Schmid, J. M., and T. E. Hinds
1974. Development of spruce-fir stands following spruce beetle outbreaks. USDA For. Serv. Res. Pap. RM-131. 16 p.

Schwandt, J. W.
1977. Dwarf mistletoe control guidelines for Idaho forests, Idaho Dept. of Lands, Div. For. Res., Bur. Private For., Rep. 77-2. 13 p.

Shea, K. R.
1963. Diameter increment in old-growth Douglas fir infected by dwarf mistletoe. Weyerhauser Co. For. Res. Note 50. 11 p.

Shea, K. R., and P. G. Belluschi
1965. Effects of dwarfmistletoe on diameter increment of immature ponderosa pine before and after partial logging. Weyerhauser For. Res. Center Pap. 4. 7 p.

Shea, K. R., and T. J. Orr
1963. A survey of dwarfmistletoe of ponderosa pine in south-central Oregon. J. For. 61:138-141.

Shea, K. R., and J. L. Stewart
1972. Hemlock dwarf mistletoe. USDA For. Serv., For. Pest Leafl. 135. 6 p.

Smith, R. B.
1969. Assessing dwarf mistletoe on western hemlock. For. Sci. 15:277-285.

Smith, R. B., and J. A. Baranyay
1970. Dwarf mistletoes in British Columbia. Canad. For. Serv., For. Res. Lab., Misc. Publ. BC-M3-71. 8 p.

Smith, R. B.
1973. Factors affecting dispersal of dwarf mistletoes on plantation grown trees in British Columbia. Can. For. Serv. Rep. BC-X-97. 21 p.

Smith, R. B., and E. F. Wass
1976. Field evaluation of ecological differentiation of dwarf mistletoe on shore pine and western hemlock. Can. J. For. Res. 6:225-228.

Stewart, J. L.
1976. Dwarf mistletoe infection from residual hemlock on cutover stands. USDA For. Serv. Res. Note PNW-278. 3 p.

Strand, M. A.
1973. Simulation of population changes of western dwarf mistletoe on ponderosa pine. Ph.D. Thesis, Oregon State University, Corvallis.

Strand, M. A., and L. F. Roth
1976. Simulation model for spread and intensification of western dwarf mistletoe in thinned stands of ponderosa pine saplings. Phytopathology 66:888-895.

Struble, G. R.
1965. Attack pattern of mountain pine beetle in sugar pine stands. USDA For. Serv. Res. Note PSW-60. 7 p.

Wagener, W. W.
1961. Forty years of dwarfmistletoe on a ponderosa pine plot near Quincy, California. USDA For. Serv., PSW For. Dis. Res. 4600 (file). 15 p.

Wagener, W. W.
1965. Dwarfmistletoe removal and reinvasion in Jeffrey and ponderosa pine, northeastern California. USDA For. Serv. Res. Note PSW-73. 8 p.

Wass, E. F.
1976. Ecology of shore pine stands infested with dwarf mistletoe. Can. For. Serv. BC-X-142. 33 p.

Waters, W. E.
1976. Evaluation of insect impacts on forest productivity and values. In The Bases for Integrated Pest Management. Proc. XVI IUFRO World Congr., Group 6, Oslo, Norway. 28 p.

Weaver, H.
1974. Effects of fire on temperate forests: Western United States, p. 279-319. In Fire and Ecosystems. Kozlowski, T. T. and C. E. Ahlgren, eds. Academic Press, New York. 542 p.

Weir, J. R.
1916. Larch mistletoe:some economic considerations of its injurious effects. USDA Bull. 317. 25 p.

Weir, J. R.
1918. Effects of mistletoe on young conifers J. Agric. Res. 12:715-718.

Wicker, E. F.
1967. Seed density as a klendusic factor of infection and its impact upon propagation of Arceuthobium spp. Phytopathology 57: 1164-1168.

Wicker, E. F.
1974a. Ecology of dwarf mistletoe seed. USDA For. Serv. Res. Pap. INT-154. 28 p.

Wicker, E. F.
1974b. Arceuthobium douglasii: its absence from the flora of the Puget-Willamette lowlands. Northw. Sci. 48:239-244.

Wicker, E. F., and C. D. Leaphart
1976. Fire and dwarf mistletoe (Arceuthobium spp.) relationships in the northern Rocky Mountains. Proc. Montant Tall Timbers Fire Ecology Conference and Fire and Land Management Symposium, No. 14, Missoula, Montana. 1974. p. 279-298.

Wicker, E. F., and C. G. Shaw
1967. Target area as a klendusic factor in dwarf mistletoe infections. Phytopathology 57:1161-1163.

Williams, W. T., F. Fortier, and J. Osborn
1972. Distribution of three species of dwarf mistletoe on their principal pine hosts in the Colorado Front Range. Plant Dis. Rep. 46:223-226.

Control Planning and Decisionmaking

CONTROL PLANNING AND DECISIONMAKING[1]

WILFRED L. FREEMAN, JR.[2]

Abstract: Decisions about dwarf mistletoe control are made by a process common in forest pest management and, indeed, common in forest resource management. The decisionmaking process is examined in detail, to show its logic, to demonstrate that landowners or resource managers are the decisionmakers, to review what inputs and decisions have to be made in the process, and to clarify the responsibilities of forest pest management (and other) specialists in the process. The point is made that today's landowners and resource managers typically need information that only specialists can provide, and that specialists are not informed enough to make sound land management decisions.

INTRODUCTION

In this panel we are to discuss the topic "Control Planning and Decisionmaking" -- or the how, when, and where of control decisions and the information base needed to make sound decisions. The essential steps of the control decision process will be outlined, with the objectives of 1) indicating that there is a logical sequence of events leading to control decisions, and 2) providing a reference framework into which the remarks and contributions from others in the field may be placed.

The control-decision process is made up of a logical sequence of steps leading to answers to the questions, "Do I control?" and, "How do I control?" The answers to these questions should be based on information about the stands, pest-caused losses, management goals, environmental and social considerations, and control options. As I briefly go through the steps in the control-decision process, I will indicate which steps are information gathering -- and what information is needed and where you might best get it -- and those steps that are decisionmaking. I will indicate who should make the decision, and what kinds of decisions might be made.

What I am describing -- the processes of informed decisionmaking which are used by forest landowners and resource managers -- is not unique to dwarf mistletoe work. Whether and how a landowner or resource manager reacts to dwarf mistletoe is determined by processes used in deciding what to do about many other things affecting him and his forest resources. Those who provide technical advice and assistance to landowners and resource managers, therefore, should know the kinds of information needed and the value of this information to the decisionmaking process.

PATHWAY TO CONTROL DECISIONS

The steps in the decision process are arranged into a flowchart (fig. 1) and will be discussed in the logical order in which they occur in the process.

Step 1: "Detection of Pest Activity." -- A pest activity on the forest is detected. I say "pest activity" because, at this point, it is yet to be determined if it is a problem. Pest detection takes place in several ways. For example, it may occur as a casual observation, as in the course of a forest management inventory: or, it may be the result of a pest survey. Indications of pest activity include the appearance of the pest, signs of tree damage, loss of growth, or tree death.

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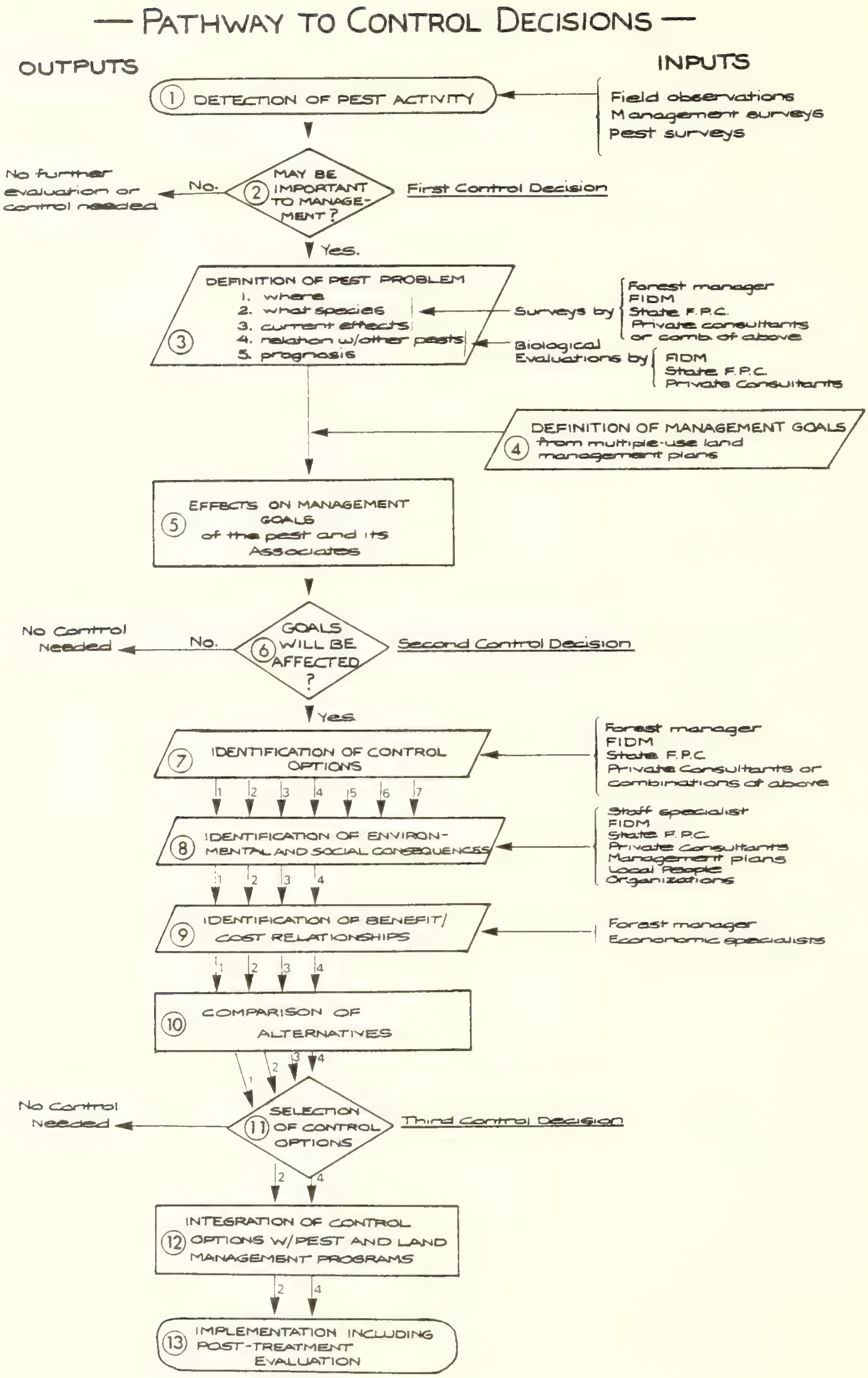
— PATHWAY TO CONTROL DECISIONS —
OUTPUTS
INPUTS
1 DETECTION OF PEST ACTIVITY
Field observations
Management surveys
Pest surveys
No further evaluation or control needed
No.
2 MAY BE IMPORTANT TO MANAGEMENT?
First Control Decision
Yes.
3 DEFINITION OF PEST PROBLEM
1. where
2. what species
3. current effects
4. relation w/other pests
5. prognosis
Surveys by
Forest manager
FIDM
State F.P.C.
Private consultants
or comb. of above
Biological Evaluations by
FIDM
State F.P.C.
Private Consultants
4 DEFINITION OF MANAGEMENT GOALS from multiple-use land management plans
5 EFFECTS ON MANAGEMENT GOALS of the pest and its Associates
No Control Needed
No.
6 GOALS WILL BE AFFECTED ?
Second Control Decision
Yes
7 IDENTIFICATION OF CONTROL OPTIONS
Forest manager
FIDM
State F.P.C.
Private Consultants or combinations of above
1
2
3
4
5
6
7
8 IDENTIFICATION OF ENVIRONMENTAL AND SOCIAL CONSEQUENCES
Staff specialist
FIDM
State F.P.C.
Private Consultants
Management plans
Local People
Organizations
1
2
3
4
9 IDENTIFICATION OF BENEFIT/COST RELATIONSHIPS
Forest manager
Economic specialists
1
2
3
4
10 COMPARISON OF ALTERNATIVES
1
2
3
4
No Control Needed
11 SELECTION OF CONTROL OPTIONS
Third Control Decision
2
4
12 INTEGRATION OF CONTROL OPTIONS W/PEST AND LAND MANAGEMENT PROGRAMS
2
4
13 IMPLEMENTATION INCLUDING POST-TREATMENT EVALUATION

Figure 1--The pathway to control decisions is a logical step-wise progression in 13 steps.

Step 2: "First Control Decision." -- At the time the pest activity is detected, or shortly thereafter, someone is required to make the first control decision, and this decision begins the process. Essentially, this first decision is based on the question, "Might this pest activity be important in the management or ownership of this forest or stand?" If the answer is "no" -- that in the owner or manager's estimation the pest does not pose a problem to his ownership or management objectives -- the process ends and no further action is required. A "no" answer can result from such things as low damage levels, damage to noncommercial species, and management constraints. If the answer is "yes," we proceed to Step 3.

Step 3: "Definition of the Pest Problem." -- At this Step the biological information needed for decisionmaking is assembled. Because so much else depends on it, this information must be sound. It is not necessary, however, for the total biological information package to be prepared only by pest management specialists. To clarify, the work of getting the biological information falls in two categories. Learning where the problem is, what host trees are affected, and the current losses are jobs that can be done by the forest resource manager or landowner, as well as by specialists in Forest Insect and Disease Management (in the Forest Service), State forest pest control units, and private industry (consulting forest entomologists and pathologists). The expertise of pest management specialists should be used, however, to get the other biological information needed: the interrelationships of insects and diseases with forest conditions that have caused the situation, and the prediction of what will happen if no action is taken -- that is, expected pest-caused losses and stand development.[3/]

Step 4: "Definition of Management Goals."-- The determination of management goals is one of the most frequently overlooked steps in the control-decision process. In many single-purpose management units, the goals may be easy to define, but in multiple-use forest management units, they may be quite varied. The land and resource management plans at various administrative levels should be a good source of information for defining the objectives of the particular unit.

Step 5: "Pest Effects on Management Goals."-- Now that the landowner or resource manager has information on the effects of the pest or pests from Step 3 and has assembled the management goals for the unit (Step 4), he examines them together here. His purpose is to learn if the pest-caused damage is affecting his current management goals adversely to any significant degree, and whether it may prevent the achievement of future goals. He has enough information to make some first estimates of how serious the losses are and will be. When losses are not serious, they are referred to as having "no negative effect." Examples of no negative effect from pest damage might be scattered mortality in wilderness or roadless areas, growth loss in recreation areas, and scattered mortality in unthinned, overstocked, young non-merchantable timber stands.

Step 6: "Second Control Decision." -- In this Step the landowner or resource manager can now make the second control decision by answering the question "Is the pest problem keeping me from reaching my management goals?" The answer to this question was developed in Step 5 Again, if the answer to this question is "No, the pest is not affecting the attainment of management goals," then no control efforts are needed and the process ends. If the answer is "yes," we proceed to Step 7.

Step 7: "Identification of Control Options." -- After a decision that goals are adversely affected, the landowner or resource manager needs to identify the control options available. They may include mechanical, biological, chemical, or cultural approaches to control. Assistance to the forest manager in identifying the options is available from FIDM, State forest pest control staffs, private consultants, or combinations of the above.

Step 8: "Identification of Environmental and Social Consequences." -- This is another input step, but it can have the effect of eliminating certain control options from further consideration. Here the environmental and social consequences of taking no action at all are identified and arrayed with the consequences associated with each alternative control option. A control option calling for clearcutting on a steep slope with unstable soil could be eliminated here. Also, one calling for removal of all overstory trees in a heavily used recreation area could be eliminated. Assistance in identifying environmental and social considerations, is available from management plans and specialists in wildlife, archeology, hydrology, recreation and other disciplines. Input may be needed from local people who could be affected or interested, organizations, governmental agencies, politicians, and others. Some insights

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[3/] When pest management specialists undertake all the work described in this step, they refer to it as "biological evaluation."

are available from forest pest management specialists (Forest Service, State, and private industry) in identifying the environmental and social effects of control options.

Step 9: "Identification of Benefit/Cost Relationship." -- In this final input step, the economic effects of taking no action at all and of taking each of the alternative control options are determined. Economic values are applied to information from Steps 3 and 5: current and predicted effects of the pest on management goals. Assigning realistic economic values to resources is a job familiar to the landowner or resource manager. He may do it himself or he may have specialists who assist him with it. Sometimes the job of economic evaluation is very difficult, because in fact the process requires the assignment of human values to damaged or undamaged forest resources, and human values are more than just monetary, measurable in dollars. Examples of things that have difficult-to-measure human values include: seeing wildlife, experiencing peace, feeling solitude, having a forest setting for recreation, identifying with the living force of a forest environment, feeling the great ages represented in forests, and witnessing the cycle of life and death in forest ecology. Complicated and controversial or not, human values involved in a pest situation must be identified and weighed by the decisionmaker in any benefit/cost relationship.

The role of pest management specialists in this Step is to identify the resources affected by the insect or disease and to help quantify the damage to those resources of concern to the landowner or resource manager. When the benefit/cost relationships have been clarified, the decisionmaker is ready to take the next step.

Step 10: "Comparison of Alternatives." -- In this Step the landowner or resource manager compares the control options available to him. He examines and contrasts the biological, environmental, social, and economic consequences of taking no action at all, and of taking each of the alternative control actions that were identified for him.

In the Forest Service it is at this step in the decisionmaking process that the Environmental Analysis Report is written. Missing from the completed report, of course, is a statement of what the decision is, and why; that comes at the next Step. At this step, the job is to assemble all of the information that will be considered in making that decision. This documentation of the information considered in making decisions that affect the environment is a requirement of the National Environmental Policy Act.

Step 11: "Selection of Control Options." -- After comparing the various alternative actions he might take and the consequences of each, the landowner or resource manager makes his decision at this Step. He may decide on no control action at all. Or he may select more than one option -- he might select a chemical control for immediate suppression and a cultural control for long-term prevention.

Step 12: "Integration of Control Options with Land and Pest Management Programs." -- In this Step, the landowner or resource manager plans the meshing of the control activities into his program of work in order to reach his objectives effectively, efficiently, and with as little disruption of his other resource management activities as possible. The investment of manpower, equipment, and dollars for control must be timed and given whatever priority is appropriate. The planned action could clash with other pest management programs in the same forested area. For example, a thinning operation for pine dwarf mistletoe control would produce slash in which *Ips* beetles could build up, later attacking the residual stand. Timing the thinning operation would be one of several possible ways to prevent that problem. In general, a pest management specialist should assist the landowner or resource manager in planning the implementation of the control action.

Step 13: "Implementation, Including Post-Treatment Evaluation." -- The planning and decisionmaking processes should lead to action. It has been argued that sound business and sound management result, as a matter of course, in an examination of whether or not the objectives of any particular action are met. Nevertheless, that does not happen often enough. Yet a pest management specialist must invest resources where there are pay-offs, and must document them. Therefore, the pest management specialist needs to work with resource managers who will use his expert knowledge, and needs to make sure that results of control actions are evaluated.

Post-treatment evaluation is achieved by planning, for each project, how to determine whether control objectives were met, and then making that determination. The work involved may be very simple in some projects; in others it may be complex enough to require the assistance of specialists, both in planning and in field work.

The post-treatment evaluation includes the results of any monitoring activities that were part of a project. Many projects today include monitoring as a result of the decisionmaking process. That is to say, the decisionmaker has examined the information available to him and decided on a particular action that is to have either no adverse environmental impact or else an acceptable level of impact. Without monitoring the project, he cannot demonstrate that any environmental impact was within the limits that he decided were acceptable. In the Forest Service, the Environmental Analysis Report or Environmental Impact Statement prepared for a project often states that monitoring will take place. In such projects, post-treatment evaluation is even more important.

CONCLUSIONS

This, then, is a view of the control-decision process in detail. Some of the steps described can be taken almost automatically, and others may be combined with one another in actual practice. Any process looks complicated and even artificial until it is examined in detail. Knowing what the process is, however, is essential for identifying who is responsible for doing what, and when. Too often, the roles of pest management specialists are confused with the responsibilities or prerogatives of landowners or resource managers. We do better work when we each do our own job.

SURVEY METHODS TO DETERMINE THE DISTRIBUTION AND INTENSITY OF DWARF MISTLETOES [1]

Oscar J. Dooling [2]

Abstract: Dwarf mistletoe distribution and intensity must be known to determine feasibility and priority of control measures. Surveys range from a quick estimate included in a general stand examination to a thorough investigation with large-scale maps. Accuracy and precision needed for management decisions will dictate which method to use. The 6-class system for rating dwarf mistletoe intensity is currently the best available for general use.

INTRODUCTION

The theme of this symposium is dwarf mistletoe control through forest management. Before something can be managed, you must know where it is. Because dwarf mistletoes are seed-producing plants with a limited spread potential, their occurrence tends to be spotty and concentrated, not random. It is not only important to know where dwarf mistletoes are, but also where they are not. If a significant portion of a stand is dwarf mistletoe-free, your options are broader. Conversely, if the stand is heavily infested, your options may be limited to either doing nothing or destroying the stand and starting over. Knowing the distribution of dwarf mistletoe will help you determine the feasibility or priority of a proposed action.

Knowing the infection intensity is also important. A light infection does not have a measurable impact on tree or stand growth, but a heavy infection can reduce potential volume to as little as one-seventh, or 14 percent, that of a healthy stand (On and Dooling 1969).[3] Intensity rating systems are used to quantify degree of infection for management priority determinations, to quantify growth loss and mortality, to help define suitable seed trees, and to help quantify infection hazard of overstory trees to understory stands (Hawksworth 1977). Infection intensities are also required as inputs for yield simulation models (Myers and others 1976, Myers and others 1971).

DISTRIBUTION SURVEYS

The simplest and least expensive survey is one included as part of stand examinations. The number of sample points is necessarily limited, and may give neither the accuracy nor precision required for good management planning. At the other end of the scale is a complete cruise with accurate mapping of all infected trees and infection centers. Either method may be necessary in specific circumstances, but normally something in between these extremes will provide the desired accuracy and precision at a reasonable cost.

Extensive surveys, designed to give the overall distribution over large areas can be either random or systematic. Graham (1964) determined the distribution of Arceuthobium douglasii in Douglas-fir, A. americanum in lodgepole pine, and A. laricis in western larch in western Montana by sampling townships at 10 locations. He predetermined the start of a line from a point on the road nearest the center of each township and spaced his plots at 10-chain intervals along the line. At each plot, he gathered data on infection from three concentric circular areas: 1/5-

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[1] Presented at Symposium on Dwarf Mistletoe Control Through Forest Management, Berkeley, Calif. April 11-13, 1978.

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[3] On, D., and O.J. Dooling. 1969. A study of the effect of dwarf mistletoe infection on the growth of western larch. USDA Forest Serv., 7 p. Northern Region, Missoula, Mont.

acre for sawtimber, 1/50-acre for pole sized, and 1/500-acre for saplings.

In a smaller area, Brown (1976) gathered data on distribution of A. americanum in lodgepole pine with a sampling technique that gave an intensity of one plot for every 10 acres. He took a stratified sample consisting of a prism plot for the overstory and a 1/100-acre circular plot for the understory at each sample point. He examined trees only for presence or absence of dwarf mistletoe.

In conjunction with a roadside strip survey of A. americanum in lodgepole pine, Hawksworth (1958) established starting points mechanically along roads and designated two parallel lines at least one mile long for sampling. Distance between lines was random, but was not less than 20 or more than 40 chains. He examined eight circular 1/10-acre plots per mile for presence and intensity of dwarf mistletoe infection.

In a survey of A. vaginatum subsp. cryptopodum in ponderosa pine, Hawksworth (1956) gathered data on presence and intensity of dwarf mistletoe from six random plots per mile along parallel lines spaced at 1/2-mile intervals.

Cahill (1973) recorded presence or absence of A. americanum in lodgepole pine on plots at five-chain intervals along lines spaced one mile apart. He also rated trees for infection intensity.

Bourchier (1956) cruised strips one chain wide spaced at 10-chain intervals for presence or absence of A. americanum in lodgepole pine.

A survey designed originally for determining white pine blister rust incidence (Clutter 1966) [4/] was modified by Toko and Carlson (1968) to determine presence and intensity of Arceuthobium spp. The design is a tree cluster double-sampling technique; the first part is a "hasty" examination, the second is a "detail" examination. The hasty examination consists of inspecting trees only for presence of infection from which the proportion of infected stems is estimated. The authors selected and examined three detail trees per cluster to determine number and location of infections.

Walters and Brown (1973) and Brown (1973) compared three sampling techniques for determining presence and infection intensity of A. americanum in lodgepole pine: the Stage II compartment examination used in the Rocky Mountain Region, a one-percent fixed plot sample, and third nearest tree sample on two- and four-chain grids. An analysis of their data compared to a complete cruise showed that a modified third nearest tree sample using a four-chain spacing will give acceptable precision at a reasonable cost. The sample point is a variable size plot with a maximum radius of 33 feet. Each plot is divided into four quadrants by the intersection of a base line through the plot center at right angles to the compass line. Quadrants are examined in a clockwise direction around plot center. The modified third nearest tree consists of an examination of only the third nearest host tree from the plot center in each quadrant for a maximum of only four trees per sample point.

Walters and Geils (1977) have modified the four-chain grid to an eight-chain grid for determining distribution of A. vaginatum subsp. cryptopodum in ponderosa pine. All other details are identical.

Hawksworth (1956, 1958) traversed all passable roads through several Ranger Districts by motor vehicle at less than 10 miles per hour. He recorded type of stand, size class, and intensity of dwarf mistletoe for a strip on the right side of the road. Strip width varied with the type of stand: one chain in old-growth and cutover stands, and 1/2-chain in pole stands. He recorded distances to the nearest 0.05 mile whenever changes occurred in type of stand or degree of infection. He has used this technique for A. douglasii in Douglas-fir, A. vaginatum subsp. cryptopodum in ponderosa pine, A. microcarpum in spruce, and A. americanum in lodgepole pine.

Similar roadside surveys were used in other localities for determining distribution and intensity of A. douglasii in Douglas-fir, A. laricis in western larch, and A. americanum in lodgepole pine (Graham 1959, 1960; Graham and Frazier 1962; Doidge 1973a, 1973b).

Several types of dwarf mistletoe/host infections are easily recognized from the air: A. campylopodum in ponderosa pine (Anon. 1958, 1976); A. douglasii in Douglas-fir (Anon. 1958, 1976; Aho and Anderson 1959; Hopkins 1959); A. vaginatum subsp. cryptopodum in ponderosa pine (Anon. 1976); and A. americanum in lodgepole pine (Anon. 1976, Baranyay and Bourchier 1961). Both airplanes and helicopters can be used. Locations of visible infections are sketched onto maps of suitable scale.

[4/] Clutter, J.L. 1966. A preliminary sampling design for a white pine blister rust incidence survey. 17 p. Univ. Ga., Athens, Ga.

The Canadian Forestry Service designed an integrated tape/event recorder for aerial distribution surveys of *A. pusillum* in jack pine (Robins 1972, Anon. 1973a, Ives and others 1973). The equipment consists of a four channel event recorder, a tape recorder, control boxes, and headsets for two observers, a navigator, and the pilot. They use an airplane at 500 feet above ground and 100 miles per hour. Observers record dwarf mistletoe infections at right angles to the airplane on the event recorder and make comments on the tape recorder. The navigator insures proper course, altitude, and speed, and indicates start, intermediate, and finish flight line check points on the event recorder, base map, and tape recorder. Infection occurrence is transferred from event recorder to map by a Map-O-Graph Ⓣ [5] adjusted to match event tape scale to map scale. Relevant verbal comments are also transferred to the map.

In some parasite/host combinations, dwarf mistletoe-caused mortality results in circular openings in the canopy easily visible on conventional vertical aerial photographs: *A. pusillum* in black spruce (Anderson 1949, Meyer and French 1966, Murtha 1972) and *A. americanum* in jack pine (Murtha 1972, Anon. 1973b, Muir and Robins 1973). The appearance of these openings on the photographs have been described as "moth-eaten" (Anderson 1949) or "ringworm-like" (Murtha 1972). Scales of 1:15,840 to 1:31,680 are usable (Muir and Robins 1973).

On western pines, large-scale photography taken at a low oblique angle has shown promise for detecting brooming within crowns in open-grown stands (Heller and Bega 1973).

Infra-red (false color) film for aerial detection of dwarf mistletoe was used at least as early as 1963 when Baranyay (1963) showed that *A. americanum* in lodgepole pine appeared as darkened areas in oblique, across valley photographs. He could not illustrate adequate shade differences between healthy and infected patches of trees on vertical photography (Baranyay 1968).

Infra-red aerial photography has been successfully used to detect mortality in black spruce caused by *A. pusillum* (Meyer and French 1967, Douglas 1973, [7] Douglas and others 1972, French and others 1975). In addition to old infection centers with mortality, young infection centers in which only brooming has occurred are also detectable (Meyer and French 1967, Douglas and others 1972).

Photography scales from 1:30,000 (French and others 1975) to 1:118,000 (Douglas 1973) [7] are useful for detecting *A. pusillum*-caused openings as small as 0.1 acre in black spruce. Openings of 0.25 acre are visible at a scale of 1:462,000 (Douglas 1973).

Dooling and others (1977) used a 3-person crew to examine and map the complete distribution of *A. americanum* in lodgepole pine in two sale areas in Montana. The survey crew consisted of a leader and two observers. The crew leader recorded presence of dwarf mistletoe as determined by the observers (based on presence of plants, swellings, or brooms). Each observer covered a strip two chains wide.

Distribution surveys range from simple to complex in design, and from reasonable to nearly prohibitive in cost. All these methods have valid uses. Tree species, stand structure, and proposed management action, along with accuracy and precision needed, will dictate which method to use.

INFECTION INTENSITY RATING SYSTEMS

There have been many attempts to quantify dwarf mistletoe infection on a tree basis (table 1) (Hawksworth 1977). Some systems have as few as four classes and one as many as 18. The terms "light," "medium," and "heavy" have been used in many rating systems, but have not been very well defined.

The 6-class dwarf mistletoe rating system, introduced by Hawksworth and Lusher (1956) is now the accepted standard in the Western United States and Western Canada. Hawksworth (1977) has recently discussed the 6-class system in detail and described its uses and limitations.

For the 6-class system, the live crown is divided into thirds, and each third is rated as: 0, no mistletoe; 1, light mistletoe (less than half of the branches infected); and 2,

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[5] A special projector used in mapmaking when changing scale.

[6] Anderson, R.L. 1949. Black spruce dwarf mistletoe in Minnesota. Masters Thesis, 139 p. Univ. Minn., Minneapolis, Minn.

[7] Douglas, R.W. 1973. Use of high altitude photography for forest disease detection and vegetation classification within the sub-boreal forest region. PhD Thesis, 141 p. Univ. Minn., Minneapolis, Minn.

Table 1--Rating systems used for dwarf mistletoe-infected trees (Hawksworth 1977).

Arceuthobium species (and host)	Number of Classes (including healthy)	Description	Reference
A. laricis (western larch)	5	0, healthy trees; infected rated X, XX, XXX, or XXXX based on degree of infection (not defined).	Weir 1916
A. vaginatum subsp. cryptopodum (ponderosa pine)	4	0, healthy trees without mistletoe; X, light mistletoe infection; XX, medium mistletoe infection; XXX, heavy mistletoe infection.	Korstian and Long 1922
A. americanum (jack pine)	4	0, healthy tree; X, slightly infected tree; XX, severely infected tree; XXX, very badly broomed tree.	Dowding 1929
A. douglasii (Douglas-fir) and A. vaginatum subsp. cryptopodum (ponderosa pine).	7	Six-class system. Each third of live crown rated as 0, no mistletoe; 1, less than half the branches infected; or 2, more than half the branches infected. Ratings of each third totaled. Ratings range from 0 (uninfected tree) to 6 (heavily infected).	Hawksworth and Lusher 1956, Hawksworth 1961
A. douglasii (Douglas-fir and A. laricis (western larch).	4	"None" - no visible infection; "Light" - less than one-third of crown broomed; "Medium" - one to two thirds of crown broomed; "Heavy" - more than two-thirds of crown broomed.	Pierce 1960
A. douglasii (Douglas-fir)	4	Class I - no evidence of brooming; Class II - brooming confined to lower third of crown; Class III - brooming for at least two-thirds of live crown; Class IV - brooming for at least two-thirds of live crown, and spike top developing.	Shea 1963
Arceuthobium spp. (several hosts in western Montana)	5	Live crown divided into 2 equal parts, each half was rated as 0, no infection; 1, less than one-third of branches infected; or 2, more than one-third of branches infected. Total for each half of crown added for three totals which range from 0 (no infection) to 4 (very heavy infection).	Graham 1964

Table 1--Rating systems used for dwarf mistletoe-infected trees (Hawksworth 1977) (continued).

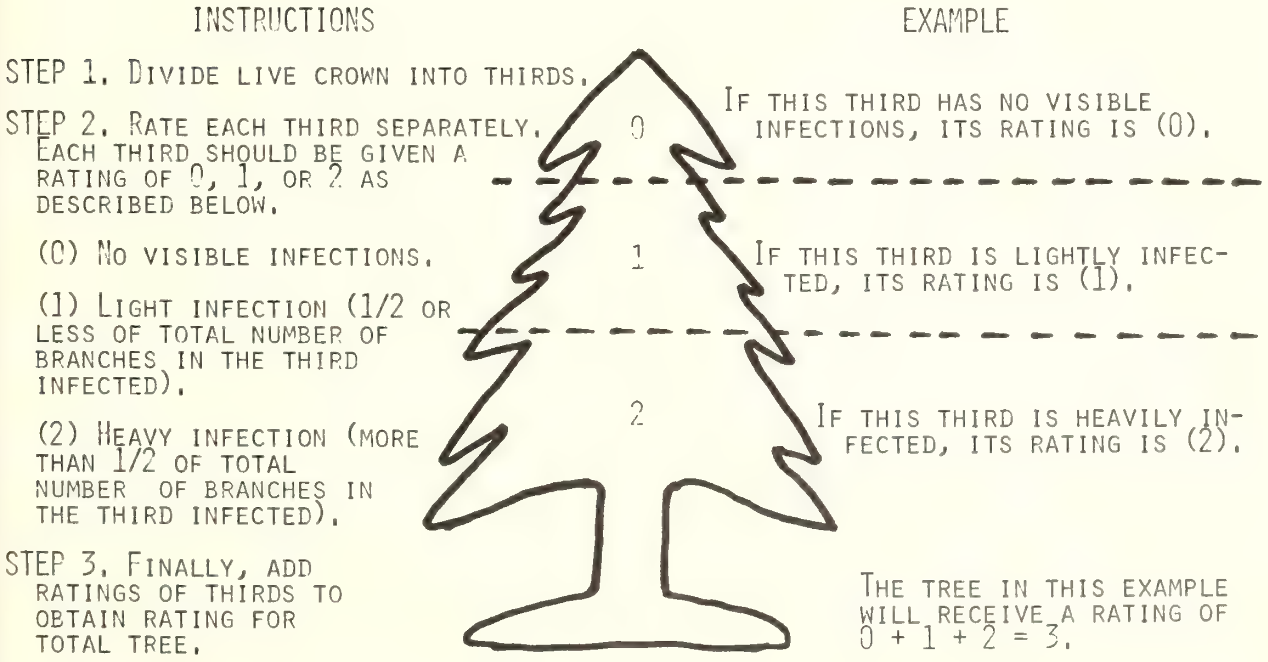
Arceuthobium species (and host)	Number of Classes (including healthy)	Description	Reference
Arceuthobium spp. (several hosts in NE Washington)	6	Same as above, but with 1 additional class for trees killed within the previous 5 years and showing symptoms or signs of having had dwarf mistletoe.	Graham and Frazier 1962
A. tsugense (western hemlock)	18	Each third of crown rated from 0.0 (no visible infections) to 3.0 (numerous large branch infections in the form of witches' brooms and at least 1 trunk swelling) by 0.5 class intervals. Rating in each third totaled for tree ratings.	Smith 1969
A. tsugense (western hemlock)	6	Middle-third rating system. Because the lower third of the tree often had numerous dead, broken, and missing branches and because the top third was often partially hidden, an analysis of growth loss in relation to the middle-third rating only was made. The results suggest that middle-third rating is superior to whole-tree rating.	Smith 1969
A. americanum (lodgepole pine)	4	0, healthy; 1, light branch infection, less than 50% of crown infected; 2, heavy branch and stem infection, more than 50% of the crown infected; 3, witches' brooms, branch and stem infections, more than 50% of the crown infected.	Baranyay and Safranyik 1970
A. abietinum (true firs)	10	Each third of crown rated as 0, no mistletoe; 1, 1-10% of branches infected; 2, 11-50% of branches infected; and 3, over 50% of branches infected. Totals added for tree rating. Note that by combining classes 1 and 2 in each third, ratings are the same as in the 6-class system.	Scharpf 1977

heavy mistletoe (more than half of the branches infected). The ratings of each third are added to obtain a total for the tree. For example, a tree heavily infected in the lower third of the crown, lightly infected in the middle third, and not infected in the upper third, would be Class 3 (fig. 1). A tree heavily infected in each third would be Class 6. The system is simple to use, and different observers tend to rate an infected tree similarly. A tree with an infection on the bole, but not the branches, is rated as Class 1. Otherwise, bole infections are not considered in the rating system.

The 6-class system was originally used for A. vaginatum subsp. cryptopodum in ponderosa pine and for A. douglasii in Douglas-fir in the Southwest (Hawksworth and Lusher 1956, Andrews and Daniels 1960, Hawksworth 1961). It was later found to be applicable to A. americanum in lodgepole pine in the Central Rockies (Hawksworth and Hinds 1964, Myers and others 1971). The system has also been applied to A. campylopodum in ponderosa pine in the Pacific Northwest (Shea 1964, Flora 1966), A. occidentale in digger pine in California (Hawksworth 1969), and A. cyanocarpum on limber pine in Colorado (Hawksworth and others 1975).

The 6-class system is also being widely used in Western Canada: A. americanum in lodgepole pine (Dobie and Britneff 1975), A. tsugense in western hemlock and shore pine (Smith and Wass 1976), and Arceuthobium spp. (Baranyay and Smith 1972).

Of the 12 rating systems proposed, the 6-class system is most widely used. It is being used for several host/parasite combinations in the Western United States and Canada. The 6-class system has been used for many purposes: to quantify height and diameter-growth loss in infected trees, to quantify infection in stands, and to select seed trees. The system does have limitations and may not be applicable to all host/parasite combinations, but it does have the strong attribute of comparability and seems to be the best currently available system for general use.



INSTRUCTIONS

STEP 1. DIVIDE LIVE CROWN INTO THIRDS.

STEP 2. RATE EACH THIRD SEPARATELY. EACH THIRD SHOULD BE GIVEN A RATING OF 0, 1, OR 2 AS DESCRIBED BELOW.

(0) NO VISIBLE INFECTIONS.

(1) LIGHT INFECTION (1/2 OR LESS OF TOTAL NUMBER OF BRANCHES IN THE THIRD INFECTED).

(2) HEAVY INFECTION (MORE THAN 1/2 OF TOTAL NUMBER OF BRANCHES IN THE THIRD INFECTED).

STEP 3. FINALLY, ADD RATINGS OF THIRDS TO OBTAIN RATING FOR TOTAL TREE.

EXAMPLE

IF THIS THIRD HAS NO VISIBLE INFECTIONS, ITS RATING IS (0).

IF THIS THIRD IS LIGHTLY INFECTED, ITS RATING IS (1).

IF THIS THIRD IS HEAVILY INFECTED, ITS RATING IS (2).

THE TREE IN THIS EXAMPLE WILL RECEIVE A RATING OF 0 + 1 + 2 = 3.

Figure 1--Instructions and example of the use of the 6-class mistletoe rating system (Hawksworth 1961, 1977).

LITERATURE CITED

Aho, P.E., and L.N. Anderson
1959. Douglas-fir dwarf mistletoe aerial survey, Rouge River National Forest 1958. USDA Forest Serv., Pacific Northwest Forest and Range Exp. Stn., Portland, Oreg. 12 p.

Andrews, S.R., and J.P. Daniels
1960. A survey of dwarf mistletoes in Arizona and New Mexico. USDA Forest Serv., Rocky Mountain Forest and Range Exp. Stn., Stn. Pap. 49, 17 p., Fort Collins, Colo.

Anonymous
1958. Annual Report 1957. USDA Forest Serv., Pacific Northwest Forest and Range Exp. Stn., Portland Oreg., p.62-63.

Anonymous
1973a. A dwarf mistletoe survey technique. Can. Forest Serv., Northern Forest Res. Centre, Alberta, Can., For. Rept. 3(2):7.

Anonymous
1973b. Dwarf mistletoe damage. Can. Forest Serv., Northern Forest Res. Centre, Alberta, Can., For. Rept. 3(3):8.

Anonymous
1976. Forest insect and disease conditions in the Intermountain States during 1975. USDA Forest Serv., Intermountain Region, Ogden, Utah, 12 p.

Baranyay, J.A.
1963. Detection of dwarf mistletoe-infected stands by aerial photography. Ann. Rept., For. Entomol. and Pathol. Branch, Can. Dep. For., Calgary, Alberta, Can., 138 p.

Baranyay, J.A.
1968. Experiment with aerial color photography for detecting dwarf mistletoe infested lodgepole pine stands in the Alberta Territories Region. Forest Res. Lab., Calgary, Alberta, Can., Internal Report. A-12, 35 p.

Baranyay, J.A., and R.J. Bourchier
1961. Province of Alberta forest disease survey. 1960 Annu. Rept. For. Ins. and Dis. Survey. Can. Forest Serv., p. 88-92.

Baranyay, J.A., and L. Safranyik
1970. Effect of dwarf mistletoe on growth and mortality of lodgepole pine stands in Alberta. Can. Dep. Fish and For. Publ. 1285, 19 p.

Baranyay, J.A., and R.B. Smith
1972. Dwarf mistletoes in British Columbia and recommendations for their control. Can. Forest Serv. Rept. BC-X-72, 18 p.

Bourchier, R.J.
1956. Province of Alberta, forest disease survey. Div. of For. Bio. Ins. and Dis. Survey Annu. Rept. 1955, p. 89-91 Calgary, Alberta, Can.

Brown, D.H.
1973. An evaluation survey procedure for dwarf mistletoe in proposed thinning projects. USDA Forest Serv., Rocky Mountain Region, 6 p. Lakewood, Colo.

Brown, D.H.
1976. Biological evaluation, dwarf mistletoe - Arapaho and Roosevelt National Forests, Redfeather Ranger District, 1974. USDA Forest Serv., Rocky Mountain Region Rept. R2-76-1, 7 p. Lakewood, Colo.

Cahill, D.B.
1973. Impact evaluation, mountain pine beetle and dwarf mistletoe, Dillon Reservoir. USDA Forest Serv., Rocky Mountain Region Timber Manage. Rept. R2-73-19,24p. Lakewood, Colo.

Dobie, J., and A.A. Britneff
1975. Lumber grades and volumes from lodgepole pine infected with dwarf mistletoe. Wood and Fiber 7:104-109.

Doidge, D.F.
1973a. Annual district report forest insect and disease survey, British Columbia, 1972, Part VI, Caribou Forest District. Can. Forest Serv., Pacific Forest Res. Centre Info. Rept. BC-X-77, 22 p. Victoria, B.C., Can.

Doidge, D.F.
1973b. Forest insect and disease conditions, 1973, Caribou District. Can. Forest Serv. Pacific Forest Res. Centre Info. Rept. BC-X-96, 10 p. Victoria, B.C., Can.

Dooling, O.J., J.D. Bortz, and M.W. Maxwell
1977. Dwarf mistletoe survey, Hebgen Lake Ranger District, Gallatin National Forest, Montana. USDA Forest Serv., Northern Region Rept. 77-13, 5 p. Missoula, Mont.

Douglas, R.W., M.P. Meyer, and D.W. French
1972. Remote sensing applications to forest vegetation classification and conifer vigor loss due to dwarf mistletoe.

NASA Earth Resources Survey Program, Final Rept., 91 p. Univ. Calif., Berkeley, Calif.

Dowding, E.S.
1929. The vegetation of Alberta III. The sandhill areas of central Alberta with particular reference to the ecology of Arceuthobium americanum Nutt. J. Ecol. 17:82-105.

Flora, D.F.
1966. A method of forecasting returns from ponderosa pine dwarf mistletoe control. USDA Forest Serv., Pacific Northwest Forest and Range Exp. Stn. Res. Pap. PNW-32, 17 p. Portland, Oreg.

French, D., M. Meyer, and F. Irving
1975. Application of remote sensing to detection and contol of dwarf mistletoe in black spruce stands. Univ. Minn., Remote Sensing Lab. Res. Rept. 75-4, 11 p. Minneapolis, Minn.

Graham, D.P.
1959. Dwarf mistletoe survey in Kootenai National Forest. USDA Forest Serv., Intermountain Forest and Range Exp. Stn. Res. Note 67, 5 p. Ogden, Utah.

Graham, D.P.
1960. Dwarf mistletoe survey in Kaniksu National Forest. USDA Forest Serv., Intermountain Forest and Range Exp. Stn. Res. Note 74, 6 p. Ogden, Utah.

Graham, D.P.
1964. Dwarf mistletoe survey in western Montana. USDA Forest Serv., Intermountain Forest and Range Exp. Stn. Res. Note INT-4, 7 p. Ogden, Utah.

Graham, D.P., and W.E. Frazier
1962. Dwarf mistletoe survey in northeastern Washington. USDA Forest Serv., Intermountain Forest and Range Exp. Stn. Res. Note 103, 8 p. Ogden, Utah.

Hawksworth, F.G.
1956. Region 3 dwarf mistletoe survey, progress report of the 1954-55 field work. USDA Forest Serv., Rocky Mountain Forest and Range Exp. Stn. Spec. Rept., 5 p. Fort Collins, Colo.

Hawksworth, F.G.
1958. Survey of lodgepole pine dwarf mistletoe on the Roosevelt, Medicine Bow, and Bighorn National Forests. USDA Forest Serv., Rocky Mountain Forest and Range Exp. Stn. Pap. 35, 13 p. Fort Collins, Colo.

Hawksworth, F.G.
1961. Dwarf mistletoe of ponderosa pine in the Southwest. U.S. Dep. Agric. Tech. Bull. 1246, 112 p.

Hawksworth, F.G.
1969. Rapid intensification and upward spread of dwarf mistletoe in inoculated digger pines. Plant Dis. Rept. 53:615-617.

Hawksworth, F.G.
1977. The 6-class dwarf mistletoe rating system. USDA Forest Serv., Rocky Mountain Forest and Range Exp. Stn. Gen. Tech. Rept. RM-48, 7 p. Fort Collins, Colo.

Hawksworth, F.G., J.T. Fisher, and R.L. Mathiasen
1975. An unusual occurrence of Arceuthobium cyanocarpum on ponderosa pine near Boulder, Colorado. Plant Dis. Rept. 59:758-759.

Hawksworth, F.G., and T.E. Hinds
1964. Effects of dwarf mistletoe on immature lodgepole pine stands in Colorado. J. For. 62:27-32.

Hawksworth, F.G., and A.A. Lusher
1956. Dwarf mistletoe survey and control on the Mescalero Apache Reservation, New Mexico. J. For. 54:384-390.

Heller, R.C., and R.V. Gega
1973. Detection of forest diseases by remote sensing. J. For. 71:18-21.

Hopkins, H.G.
1959. Salvaging mistletoe damaged timber. Proceedings, West. For. Conf., 1958, p. 36-39.

Ives, W.G., J.J. Lawrence, and J.K. Robins
1973. Prairies Region forest insect and disease survey Annu. Rept., 1972, p. 74-81. Can. Dep. Environ.

Korstian, C.F., and W.H. Long
1922. The western yellow pine mistletoe: effect on growth and suggestions for control. U.S. Dep. Agric. Tech. Bull. 1112, 35 p.

Meyer, M.P., and D.W. French
1966. Dwarf mistletoe in black spruce forests can be assessed through sequential aerial photography. Photogramm. Eng. 32:812-814.

Meyer, M.P., and D.W. French
1967. Detection of diseased trees. Photogramm. Eng. 33:1035-1040

Muir, J.A., and J.K. Robins
1973. Detection of dwarf mistletoe of jack pine on aerial photographs. Plant Dis. Rept. 57:951-954.

Murtha, P.A.
1972. A guide to air photo interpretation of forest damage in Canada. Can. Forest Serv. Publ. 1292, 62 p.

Myers, C.A., F.G. Hawksworth, and J.L. Stewart
1971. Simulating yields of managed, dwarf mistletoe-infected lodgepole pine stands. USDA Forest Serv., Rocky Mountain Forest and Range Exp. Stn. Res. Pap. RM-72, 15 p. Fort Collins, Colo.

Myers, C.A., C.B. Edminster, and F.G. Hawksworth
1976. SWYLD2: Yield tables for even-aged and two-storied stands of southwestern ponderosa pine, including effects of dwarf mistletoe. USDA Forest Serv., Rocky Mountain Forest and Range Exp. Stn. Res. Pap. RM-163, 25 p. Fort Collins, Colo.

Pierce, W.R.
1960. Dwarf mistletoe and its effect upon the larch and Douglas-fir of western Montana. Mont. State Univ. School of For. Bull. 10, 38 p. Missoula, Mont.

Robins, J.K.
1972. Dwarf mistletoe aerial surveying method: results of preliminary trials in the Athabasca Forest, Alberta, March 1972. Can. Forest Serv., Northern Forest Res. Centre Misc. Rept. NOR-Y-10, 4 p. Calgary, Alberta, Can.

Scharpf, R.F.
1977. Dwarf mistletoe does not increase trunk taper in released red firs in California. USDA Forest Serv., Pacific Southwest Forest and Range Exp. Stn. Res. Note PSW-326, 3 p. Berkeley, Calif.

Shea, K.R.
1963. Marking guide evolved for mistletoe-hit Douglas-fir. For. Indus. 90:58-59.

Shea, K.R.
1964. Diameter increment of ponderosa pine infected with dwarf mistletoe in south-central Oregon. J. For. 62:743, 746-748.

Smith, R.B.
1969. Assessing dwarf mistletoe on western hemlock. For. Sci. 15:277-285.

Smith, R.B., and E.F. Wass
1976. Field evaluation of ecological differentiation of dwarf mistletoe on shore pine and western hemlock. Can. J. For. Res. 6:225-228.

Toko, H.V., and C.E. Carlson
1968. Dwarf mistletoe survey procedure. USDA Forest Serv., Northern Region Ins. and Dis. Rept., 11 p. Missoula, Mont.

Walters, J.W., and D.H. Brown
1973. An administrative study of sampling techniques in dwarf mistletoe-infested stands. USDA Forest Serv., Rocky Mountain Region Timber Manage. Rept., 11 p. Lakewood, Colo.

Walters, J.W., and B.W. Geils
1977. Technical report - simulated yield tables for dwarf mistletoe management in ponderosa pine stands (SWYLD2 program). Phase I - two storied stands, Chalender Ranger District, Kaibab National Forest, Arizona. USDA Forest Serv., Southwestern Region Rept. R-3 77-11, 25 p. Albuquerque, N.M.

Weir, J.R.
1916. Larch mistletoe: some economic considerations of its injurious effects. U.S. Dep. Agric. Bull. 317, 25 p.

THE EXTENT OF DWARF MISTLETOE IN SIX PRINCIPAL SOFTWOODS IN CALIFORNIA, OREGON, AND WASHINGTON, AS DETERMINED FROM FOREST SURVEY RECORDS[1]

Charles L. Bolsinger[2]

Abstract: Forest inventory records show dwarf mistletoe infection in six principal softwoods (14 species) on 23 percent of the commercial forest land in California, Oregon, and Washington. Infection was most widespread in Douglas-fir (3.6 million acres), ponderosa and Jeffrey pines (3.2 million acres), and true firs (1.9 million acres). Western larch and lodgepole pine were the most seriously infected species.

INTRODUCTION

Dwarf mistletoe information recorded from 1966 to 1976 on 16,904 commercial forest inventory plots in Oregon, Washington, and California was summarized for six principal softwood groups (see table 8, appendix), by forest type, geographic area, and ownership group. The area sampled by these plots is 49,706,000 acres, about 84 percent of the total commercial forest in the three States.

Inventory plots on National Forests were established by Regions 5 and 6 of the U.S. Forest Service. The Bureau of Land Management Districts established plots on BLM land in western Oregon. Plots on other lands were established by the Renewable Resources Evaluation Research Unit of the Pacific Northwest Forest and Range Experiment Station. (See table 8, appendix, for dates of inventory and numbers of plots.)

Oregon and Washington plots were located on a systematic grid. California plots were randomly located within prestratified volume classes; each plot in a sampling unit represented about the same area. Plots on the three National Forests examined in Washington were circular and 1/5-acre in size. All trees with 5.0-inch and larger d.b.h. in the first quadrant were tallied, and all trees 11.0 inches and larger in all quadrants were tallied. In all other inventories, plots consisted of 10 points distributed over an acre. At each point, trees 5.0-inch d.b.h. and larger were tallied by prism; and trees from 6-inch height to 4.9-inch d.b.h. were tallied on fixed-radius plots, usually 1/300-acre in size. All trees were examined for the presence of dwarf mistletoe. Trees on the first three points were bored to determine growth, except on some remeasurement plots, where diameter growth was determined from successive diameter measurements.

In most areas inventoried, infections were recorded by severity classes; in National Forests in Washington, infections were not classified by severity. Before 1968 or 1969, dwarf mistletoe infections were recorded if nothing more serious affected tally trees, as judged by inventory crews. Infections were classified as light, medium, or heavy. After 1968 or 1969 a six-point rating system (Hawksworth and Lusher 1956) was used for all trees tallied.

The three-class system was equated to the six-point system and average stand dwarf mistletoe rating (DMR) was calculated for each plot (table 7, fig. 3, appendix).

Three-class system	Equivalent six-point rating system
Light infection	1
Medium infection	3
Heavy infection	5

Percent of trees 5.0-inch d.b.h. and larger infected by dwarf mistletoe also was calculated for each plot.

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[1] Presented at the Symposium on Dwarf Mistletoe Control Through Forest Management, Berkeley, California, April 11-13, 1978.

[2] Research Forester, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

Forest type was computed from tree tally data on each plot.[3] Dwarf mistletoe infections were recorded by tree species and data were summarized by species infected and by forest type.

RESULTS

Area of Infestation

Dwarf mistletoe (*Arceuthobium* spp.)-infected trees were found on about 23 percent of 16,904 commercial forest inventory plots in Oregon, Washington, and California (table 1). The area represented by the plots with dwarf mistletoe present is 11,270,000 acres.

Commercial forests west of the Cascade crest in Oregon and Washington were relatively free of dwarf mistletoe; in western Oregon and western Washington 10 percent were infected. In both eastern Oregon and eastern Washington, 41 percent of the commercial forest was infested. In California, 21 percent was infested (fig. 1 and table 1).

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[3] Resources Evaluation Research Work Unit. Forest Survey field instructions for eastern Oregon, 1977. Pac. Northwest For. and Range Exp. Stn., Portland, Oreg. (Unpublished).

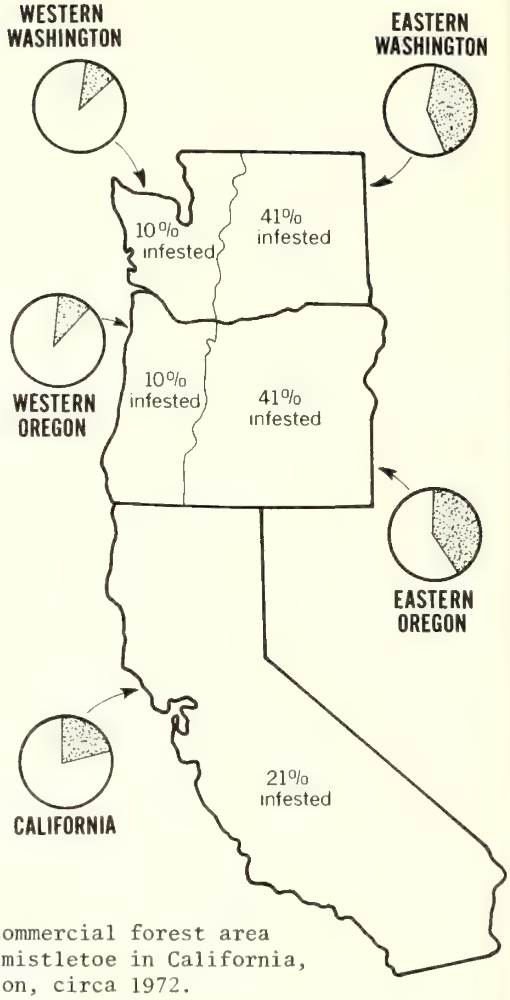


Figure 1--Percent of commercial forest area infested with dwarf mistletoe in California, Oregon, and Washington, circa 1972.

Table 1--Area of commercial forest examined for dwarf mistletoe and area infested, by State and half-State and ownership group, California, Oregon, and Washington, circa 1972

State and half-State	National Forests			All other ownerships			All ownerships		
	Total area examined	Area infested	Percent of area infested	Total area examined	Area infested	Percent of area infested	Total area examined	Area infested	Percent of area infested
	- Thousand acres - -			- Thousand acres - -			- Thousand acres - -		
California	5,911	889	15	7,658	1,779	25	13,569	2,811	21
Western Oregon	3,604	629	17	9,158	685	7	12,762	1,314	10
Eastern Oregon	5,068	1,942	38	3,556	1,629	46	8,624	3,571	41
Total or Percent	8,672	2,571	30	12,714	2,314	18	21,386	4,885	23
Western Washington	[1]184	34	18	7,774	778	10	7,958	812	10
Eastern Washington	[2]1,593	574	36	5,200	2,188	42	6,793	2,762	41
Total or Percent	1,777	608	34	12,974	2,966	23	14,751	3,574	24
Three-State Total or Percent	16,360	4,068	25	33,346	7,202	22	49,706	11,270	23

[1] Data developed only for north Mt. Baker National Forest.

[2] Data developed only for Okanogan and Wenatchee National Forests.

Douglas-fir dwarf mistletoe infections in Douglas-fir were found over 3.6 million acres (table 2). Second in area infested was ponderosa pine - 3.2 million acres. True firs infected by dwarf mistletoe were third in area - 1.9 million acres; included were grand, white, noble, California red, Shasta red, Pacific silver, and subalpine firs. Other tree species examined, in order of area infested, were lodgepole pine, western and mountain hemlocks, and western larch.

Western larch was the most heavily infested (table 3); 47 percent of the forest-type acreage had dwarf mistletoe infected trees. Lodgepole pine was second--42 percent of the forest-type was infested; other forest types: ponderosa and Jeffrey pines--26 percent of the area infested, true firs--21 percent, hemlocks--21 percent, and Douglas-fir--13 percent.

Only 12 percent of the total area infested had a dwarf mistletoe rating (DMR) greater than 2.4. At least 41 percent of all trees were infected in 29 percent of the infested stands. Tables 4 and 5 show these degrees of infestation by species and forest type.

An examination of dwarf mistletoe incidence by stand size showed a definite increase in the proportion of area infested with an increase in stand size for hemlocks, western larch, and true firs. For Douglas-fir a slight trend of increasing infection with increasing stand size was shown. No trend at all was apparent for lodgepole pine, possibly because of the large area in seedlings, saplings, and poletimber. Ponderosa pine showed a weak reverse trend (fig. 2 and table 6).

Site Relationship

All areas were classified by site index. To what degree dwarf mistletoe infections influenced the site classification is not known. Field crews were instructed to select trees free of disease or damage. Sometimes this was difficult. The data show that the distribution of dwarf mistletoe is generally proportional to site distribution for most species in most regions. Weak site preferences did appear for Douglas-fir and true firs: No Douglas-fir dwarf mistletoe was found on high sites in California, eastern Oregon, or eastern Washington; and only 1 percent of the high sites in western Oregon was infested, compared with 5 percent for medium and low sites. True fir dwarf mistletoe seemed to favor high and medium sites in all areas, but the differences shown by the sample are not conclusive. True fir infestations were distributed by site as follows:

	All areas examined	Outside National Forests in California
	- - - Percent infested - - -	
High sites	25	40
Medium sites	22	42
Low sites	20	33

Table 2--Area of commercial forest examined for dwarf mistletoe, and area infested, by species and forest type, in California, Oregon, and Washington, circa 1972[1]

Tree species and forest type[2]	Total area in type	Area in the type with type species infected[3]	Percent of type infested	Species infected in other forest types[3]	Total area in which the species is infected[3]
	- - - Thousand acres - - - -			- - - - - Thousand acres - - - - -	
Ponderosa and Jeffrey pines	8,346	2,158	26	995	3,153
Douglas-fir	16,526	2,160	13	1,415	3,575
Lodgepole pine	2,578	1,090	42	375	1,465
Western and mountain hemlocks	3,250	668	21	596	1,264
Western larch	360	168	47	869	1,037
True firs	5,710	1,219	21	718	1,937
Total or percent	36,770	7,463	20	[4]	[4]
All other species and forest types	12,936	3,807			
Total area examined	49,706	11,270	23		

[1] See table 8, appendix, for actual dates of data collection.

[2] See list of tree species and dwarf mistletoe species (table 9, appendix).

[3] Included are areas in which two or more tree species are infected.

[4] Not summable.

Table 3--Percent of commercial forest land infested by dwarf mistletoe with a dwarf mistletoe rating (DMR) of 2.41 and greater, and with infections in 41 percent or more of all trees tallied

Species and forest type	DMR 2.41+	Infections in 41 percent or more of all trees tallied
	Percent of total infested area	
Ponderosa and Jeffrey pines	11	32
Douglas-fir	7	19
Lodgepole pine	20	52
Hemlocks	14	29
Western larch	37	50
True firs	8	20

Table 4--Area of commercial forest land infested by dwarf mistletoe, by species and forest type, and by average stand dwarf mistletoe rating, California, Oregon, and Washington, circa 1972

Species and forest type	Infection only in trees less than 5.0" d.b.h.	Average stand dwarf mistletoe rating in trees 5.0"+			Total area infested[1]
		0.01-1.00	1.01-2.40	2.41+	
	Thousand acres				
Ponderosa and Jeffrey pines	141	1,363	378	245	2,127
Douglas-fir	73	1,419	219	122	1,833
Lodgepole pine	117	489	246	213	1,065
Hemlocks	25	426	100	93	644
Western larch	0	66	24	52	142
True firs	74	914	112	99	1,199
Total	430	4,677	1,079	824	7,010
	Percent				
Percent	6	67	15	12	100

Table 5--Area of commercial forest land infested by dwarf mistletoe, by species and forest type and by percent of trees infected, California, Oregon, and Washington, circa 1972

Species and forest type	Percent of trees 5.0" d.b.h. and larger infected				Total area infected[1]
	1-20	21-40	41-60	61+	
	Thousand acres				
Ponderosa and Jeffrey pines	975	354	189	478	1,986
Douglas-fir	1,114	325	124	197	1,760
Lodgepole pine	312	139	153	344	948
Hemlocks	328	111	57	123	619
Western larch	14	57	19	52	142
True firs	745	162	73	145	1,125
Total	3,488	1,148	615	1,329	6,580
	Percent				
Percent	53	18	9	20	100

[1] These totals are less than shown in table 2 because severity of dwarf mistletoe infections are not rated in all areas. Excludes stands in which infection was only in trees less than 5-in. d.b.h.

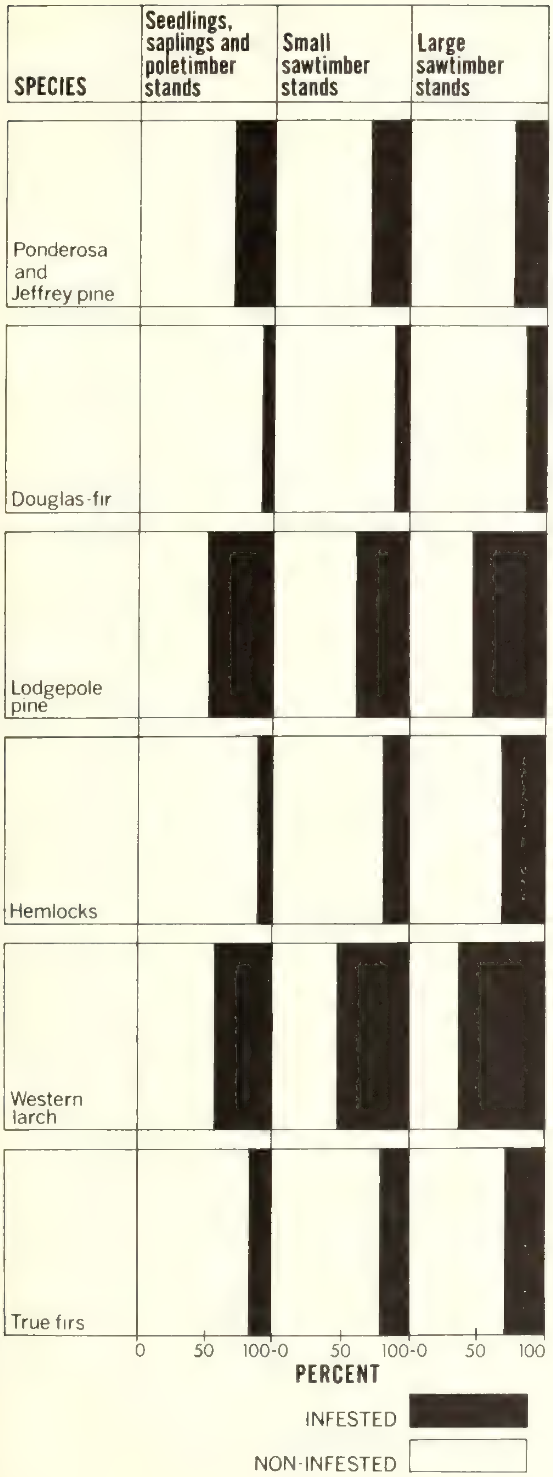


Figure 2--Proportion of area infested with dwarf mistletoe by forest-type species and stand size class, California, Oregon, and Washington

Infestation by Species

Ponderosa and Jeffrey pines

Ponderosa pine dwarf mistletoe was most plentiful and infections were most severe in eastern Oregon, though this disease was found throughout most of the range of ponderosa and Jeffrey pines in the three States. About 32 percent of the total area of ponderosa and Jeffrey pine infections in the three States was in forest types other than ponderosa or Jeffrey pine. In California almost half of the dwarf mistletoe infected ponderosa and Jeffrey pines occurred in other forest types, mainly incense-cedar and hardwoods. In Oregon and Washington about 25 percent was in other forest types, mostly Douglas-fir and true firs.

Douglas-fir

Most of the Douglas-fir region--the area west of the Cascades in Oregon and Washington and northwestern California--is free of Douglas-fir dwarf mistletoe. Most of the dwarf mistletoe found in the Douglas-fir region was in the Klamath Mountains of southwestern Oregon and northwestern California. Douglas-fir forests east of the Cascades were heavily infested--42 percent of the Douglas-fir type in eastern Oregon and 43 percent in eastern Washington.

In all three States combined, about 40 percent of the area infested with Douglas-fir dwarf mistletoe was in types other than Douglas-fir, most commonly true fir. In California, 52 percent of the area infested with Douglas-fir dwarf mistletoe was in other types.

Lodgepole Pine

Dwarf mistletoe was not found in the few widely scattered stands of lodgepole pine in western Oregon and western Washington but was common in other areas. In eastern Oregon, outside National Forests, 55 percent of the lodgepole pine type was infested. In the pumice region of central Oregon, the author has observed that dwarf mistletoe in lodgepole pine is typically associated with infections of gall rust (*Endocronartium harknessii* [Moore]).

Western and Mountain Hemlocks

The only serious dwarf mistletoe threat in the Douglas-fir region seems to be in hemlock but occurrence is scattered. Extensive areas are entirely free of this disease. Three locations in which the author has noted severe hemlock dwarf mistletoe damage are Larch Mountain in Oregon's Cascades, the westside of the Olympic Peninsula in Washington, and the Nooksak River drainage in northern Washington. Nearly half of

Table 6--Area of commercial forest land examined for dwarf mistletoe and area infested by species and forest type and by stand size class, California, Oregon, and Washington, circa 1972

Species and Forest type[1]	Seedling-sapling and poletimber			Small sawtimber			Large sawtimber		
	Total area	Infested area		Total area	Infested area		Total area	Infested area	
	Thousand acres		Percent	Thousand acres		Percent	Thousand acres		Percent
Ponderosa and Jeffrey pines	2,421	740	30.6	3,064	788	25.7	2,538	603	23.7
Douglas-fir	4,487	320	7.1	5,197	533	10.2	6,087	637	10.5
Lodgepole pine	1,615	752	46.6	636	235	36.9	151	77	51.0
Hemlocks	1,008	101	10.0	941	169	18.0	1,158	375	32.4
Western larch	162	63	38.9	112	61	54.5	29	19	65.5
True firs	1,164	197	16.9	1,968	381	19.4	2,378	620	26.0

[1] This table includes only infections in the tree species for which type was named.

the hemlock dwarf mistletoe infestations are in other forest types; included are Douglas-fir, true fir and red alder.

Western Larch

Western larch is found on the east slopes of the Cascades from near Bend, Oregon, north to Canada and in the Blue Mountains, the Okanogan Highlands, and the Selkirk Mountains. Only in the Selkirks are there extensive areas of larch type. Most of the larch occurs in other types; therefore, most of the area infested with larch dwarf mistletoe--84 percent--was in other types, usually Douglas-fir or true firs. Also included were Engelmann spruce, lodgepole pine, and ponderosa pine. In many areas, it is difficult to find larch trees 21.0-inch d.b.h. or larger that are not infected. Forest managers and planners consider dwarf mistletoe to be a significant factor related to the high mortality in larch measured in recent inventories in eastern Oregon and eastern Washington.

True Firs

California has 46 percent of the true fir type examined in the study but 53 percent of the area infested with true fir dwarf mistletoe. Outside National Forests in California, 38 perce of the true fir types were found to be infected. In the Klamath Mountains in the southwest corner of Oregon, true fir dwarf mistletoe was usually found in the same stands as Douglas-fir dwarf mistletoe. In all areas, 37 percent of true fir dwarf mistletoe infections were in other types.

LITERATURE CITED

Hawksworth, Frank G., and Lusher, Arthur A.
1956. Dwarf mistletoe survey and control on the Mescalero-Apache Reservation, New Mexico J. For. 54:384-390, illus.

Kimmey, James W.
1957. Dwarf mistletoes of California and thei control, USDA Forest Serv. Tech. Pap. No. 19 Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif. 12 p.

APPENDIX

Table 7--Dwarf mistletoe infestation

3-class rating system

Infection	Seedlings or saplings	Poletimber or sawtimber
	(Trees 6 inches high to 4.9 inch d.b.h.)	(Poletimber 5.0- to 8.9-inch d.b.h.; sawtimber 9.0-inch + d.b.h.)
Light	No more than two separate infections per tree. All infections more than 12 inches from bole.	Infections confined to lower third of crown. May have few developing witches broom in lower third of crown.
Medium	Three to six separate infections per tree with all infections at least 12 inches from bole.	Lower two-thirds of crown infected.
Heavy	More than six separate infections or fewer if within 12 inches of bole, or one infection on bole.	Infection through entire crown or in upper third. Spike tops may may be developing.

6-POINT RATING SYSTEM

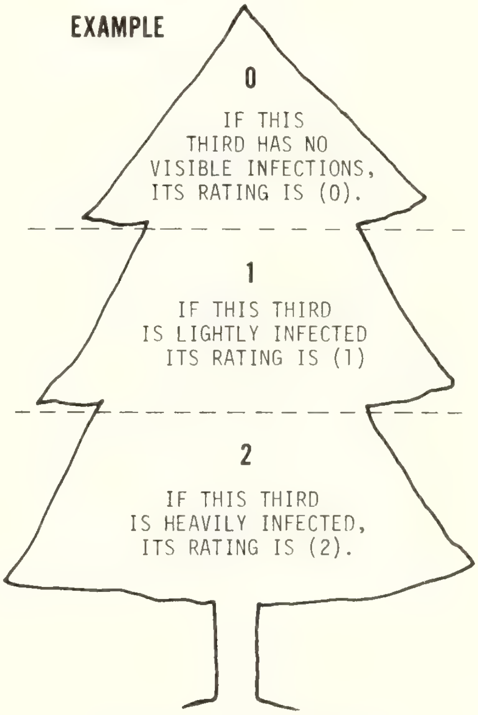
INSTRUCTIONS

Step 1. DIVIDE LIVE CROWN INTO THIRDS.

Step 2. RATE EACH THIRD SEPARATELY. EACH THIRD SHOULD BE GIVEN A RATING OF 0, 1 OR 2 AS DESCRIBED BELOW.
(**0**) NO VISIBLE INFECTIONS.
(**1**) LIGHT INFECTION (1/2 OR LESS OF TOTAL NUMBER OF BRANCHES IN THE THIRD INFECTED).
(**2**) HEAVY INFECTION (MORE THAN 1/2 OF TOTAL NUMBER OF BRANCHES IN THE THIRD INFECTED).

Step 3. FINALLY, ADD RATINGS OF THIRDS TO OBTAIN RATING FOR TOTAL TREE.

EXAMPLE



IF THIS THIRD HAS NO VISIBLE INFECTIONS, ITS RATING IS (0).

IF THIS THIRD IS LIGHTLY INFECTED ITS RATING IS (1)

IF THIS THIRD IS HEAVILY INFECTED, ITS RATING IS (2).

THE TREE IN THIS EXAMPLE WILL RECEIVE A RATING OF 0 + 1 + 2 = 3.

Figure 3--Six-point dwarf mistletoe rating system

Table 8--Number of inventory plots examined for dwarf mistletoe by date, State, and unit and dwarf mistletoe rating system, California, Oregon, and Washington

State and Unit	Inventory Date	Dwarf Mistletoe Rating System	Number of Plots
California			
National Forests			
Klamath	1967	3-class	571
Lassen	1970	6-point	224
Mendocino	1971	6-point	236
Modoc	1970	6-point	240
Plumas	1969	3-class	260
Shasta	1968	3-class	212
Six Rivers	1966	3-class	398
Tahoe	1972	6-point	261
Trinity	1969	3-class	182
			2,584
Outside National Forests			
Humboldt County	1966	3-class	262
Mendocino County	1967	3-class	257
Siskiyou County	1968	3-class	135
Rest of State exclusive of Southern California	1970-1972	6-point	993
			1,647
Total for California			4,231
Western Oregon			
National Forests			
Mount Hood	1971	6-point	421
Rogue River	1967	3-class	300
Siskiyou	1968	3-class	400
Siuslaw	1973	6-point	487
Umpqua	1969	6-point	749
Willamette	1971	6-point	589
			2,946
Bureau of Land Management	1967-1969	3-class	1,828
Outside National Forests	1973-1976	6-point	953

(continued)

Table 8--Number of inventory plots examined for dwarf mistletoe by data, State, and unit and dwarf mistletoe rating system, California, Oregon, and Washington

State and Unit	Inventory Date	Dwarf Mistletoe Rating System	Number of Plots
Eastern Oregon			
National Forests			
Deschutes	1971	6-point	712
Fremont	1973	6-point	430
Ochoco	1972	6-point	291
Umatilla	1968	3-class	749
Wallowa-Whitman	1968	3-class	639
Winema	1972	6-point	383
			3,204
Outside National Forests			
Central Oregon	1964	3-class	334
Blue Mts.	1969	6-point	246
			580
Total for Oregon			9,511
Western Washington			
North Mt. Baker National Forest	1965	Not rated	102
Outside National Forests			
Southwest Washington	1963	3-class	461
Olympic Peninsula	1965	3-class	487
Puget Sound	1966	3-class	546
			1,494
Eastern Washington			
National Forests			
Okanagan and Wenatchee	1964-1965	Not rated	885
Outside National Forests			
Central Washington	1967	3-class	369
Inland Empire	1968	3-class	414
			783
Total for Washington			3,162
Total for all three States			16,904

Table 9--List of tree species and most commonly associated dwarf mistletoe species[1]

Common name	Scientific name	Dwarf mistletoe[2]
Ponderosa pine	*Pinus ponderosa* Laws.	*Arceuthobium campylopodum* Engelm.
Jeffery pine	*Pinus jeffreyi* Grev. and Balf.	*Arceuthobium campylopodum* Engelm.
Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco	*A. douglasii* Engelm.
Lodgepole pine	*Pinus contorta* Dougl.	*A. americanum* Nutt.
Western hemlock	*Tsuga heterophylla* (Raf.) Sarg.	*A. tsugense* (Rosend.) G. N. Jones
Mountain hemlock	*Tsuga mertensiana* (Bong.) Carr.	*A. tsugense* (Rosend.) G. N. Jones
Western larch	*Larix occidentalis* Nutt.	*A. laricis* (Piper) St. John
Pacific silver fir	*Abies amabilis* (Dougl.) Forbes	*A. tsugense* (Rosend.) G. N. Jones
White fir	*A. concolor* (Gord. & Glend.) Lindl.	*A. abietinum* (Engelm.) Gill
Grand fir	*A. grandis* (Dougl.) Lindl.	*A. douglasii* (Engelm.)
Subalpine fir	*A. lasiocarpa* (Hook.) Nutt	*A. laricis* (Piper) St. John
California red fir	*A. magnifica* A. Murr.	*A. abietinum* (Engelm.) Gill
Shasta red fir	*A. magnifica* var *shastensis* Lemm.	*A. abietinum* (Engelm.) Gill
Noble fir	*A. procera* Rehd.	*A. tsugense* (Rosend.) G. N. Jones

[1] See footnote 3 in text, Kimmey 1957, and Graham, Donald P. 1964, The dwarf mistletoes, their characteristics and identification. USDA For. Serv. Reg. 6, Portland, Oreg. 7 p. (Unpublished).

[2] Listed are the species of *Arceuthobium* most commonly infecting the tree species listed. No attempt was made to identify the species of *Arceuthobium*, though more than one may infect some tree species. The area of lodgepole pine shown in this report to be infected with dwarf mistletoe, for example, may include infections of *A. americanum*, *A. laricis*, *A. campylopodum*, or *A. tsugense*.

APPROACHES TO DETERMINING VOLUME LOSSES DUE TO DWARF MISTLETOE ON A WESTWIDE BASIS[1]

David B. Drummond[2]

Abstract: Timber inventory data from three National Forests were evaluated to determine their suitability as a source of data which could be used to compute cubic-foot volume loss. These data indicate that while timber inventory and forest survey represent the logical approach to the collection and storage of such information, existing data are not adequate to provide cubic-foot volume loss estimates at this time. Results from a road-plot survey indicate that the system can be used to estimate dwarf mistletoe incidence and intensity in areas where all topographic aspects contain adequate roads.

INTRODUCTION

Information on forest insect- and disease-caused losses over large areas has usually been available only by extrapolating timber stand data initially collected for other purposes. Few attempts have been made to relate disease incidence to volume loss at a statewide level. In the past, confidence limits could not be placed on national estimates of insect- and disease-related losses, and they were often disregarded. To rectify this, we are attempting to assess loss from dwarf mistletoe and other forest pests over a statewide area. To help in planning and carrying out this attempt, the U.S. Forest Service organized a Loss Assessment Working Group composed of forest pathologists.

At first glance, statewide estimates of forest insect- and disease-caused loss would appear to be of little benefit to the timber manager at the district level. Indirect values to the timber manager, however, include (1) the determination of long-term effects of a pest or pest complex on growth which will help establish priorities in management; (2) the documentation of the success or failure of silvicultural and/or direct control measures applied by the timber manager (these estimates will assure that research support is provided for problems of greatest concern to the timber manager); and (3) the reduction in the amount of management by crisis--a syndrome often displayed by the Forest Service in its dealings with pests. Furthermore, data of this nature will aid in allocating funds when needed.

The estimates per se, if made for an entire forest, state, or region, will be of little direct value to the timber manager in dealing with specific stands. However, data from which such estimates were drawn would be of use to him if they were located in a common data base.

TIMBER INVENTORY AS A FUTURE SOURCE OF LOSS DATA

Remote sensing techniques are coming into wide use, but dwarf mistletoes do not lend themselves well to detection using such techniques. In most areas, greatest losses are attributed to reduced growth, not mortality; consequently, these losses are often ignored.

To measure the effects of dwarf mistletoes and other pathogens, data need to be collected over large areas, and data collection should be repeated at specified intervals. This reevaluation is most important. Growth loss caused by forest pests must be studied during the endemic phase so that host-pathogen interactions at that level can be documented. In this way, it can be determined if a particular pest causes sufficient loss at normal population levels to alter existing management strategy.

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[1] Presented at the Symposium on Dwarf Mistletoe Control Through Forest Management, Berkeley, Calif. April 11-13, 1978.

[2] Survey Plant Pathologist, Forest Insect and Disease Management Methods Application Group, USDA Forest Service, Davis, Calif.

Research has documented the effects of mistletoes on a stand-by-stand basis (Baranyay and Safranyik 1970; Hawksworth and Hinds 1964; Weir 1916), and these results have been incorporated into simulation models for lodgepole pine and southwestern ponderosa pine (Edminster 1977). These tools can aid in estimating loss on a state or regional basis.

The Loss Assessment Working Group agreed that the timber inventory would provide the best way to fulfill these data collection requirements; however, existing timber inventory data are not adequate to provide reliable disease and insect information. Generally, information concerning pests available in the inventory is not adequate to assess insect or disease presence at the stand level, nor is it sufficiently consistent for estimates of disease loss over large areas. Insect and disease information in many regional inventories consists of a subjective evaluation of only the "most damaging agent" observed on each plot tree. This does not permit accurate determination of specific pest organisms involved in complexes or the relative importance of other organisms endemic in the area. We hope eventually to alter slightly the various timber inventory methods to improve the quality and quantity of pest data collected; in the meantime, we hope to generate loss estimates by using several approaches.

In the interim, we are evaluating existing dwarf mistletoe incidence data, and where possible, use those data that appear adequate to provide an interim volume loss estimate. We are also investigating methods of rapidly acquiring accurate data for areas where either timber inventory and/or dwarf mistletoe incidence data are not available, i.e., private and state ownerships.

This paper describes approaches used to estimate losses due to dwarf mistletoes on three National Forests: the Medicine Bow in Wyoming, the Prescott in Arizona, and the Deschutes in Oregon.

GATHERING LOSS ASSESSMENT INFORMATION

Medicine Bow
National Forest, Wyoming

During 1977, a pilot project was conducted on the Medicine Bow National Forest in Wyoming. The purpose of this survey was to evaluate an existing timber inventory system that included a dwarf mistletoe rating (Hawksworth 1956), in addition to the "most damaging agent" evaluation of plot trees. These timber inventory data were compared with results of a road-plot survey, carried out by forest pathologists during the summer. The survey was intended to test our ability to estimate green stand parameters and, at the same time, determine if timber inventory crews accurately evaluated the presence of dwarf mistletoe.

Road Plot Survey

The survey was similar in design to one conducted by Hawksworth (1958), but with some modifications. The study consisted of two parts. The first part was a road reconnaissance where the distance was recorded at any point where a detectable change in forest type, size class, or dwarf mistletoe infection level occurred along the right-hand side of the road. Type maps were used to exclude obvious areas of non-lodgepole pine type. Lodgepole pine stands above 3,000 m elevation were also excluded because lodgepole pine dwarf mistletoe does not occur above this elevation in the Medicine Bow National Forest (Hawksworth 1956). Inventory data were used to provide acreage estimates for lodgepole pine type on the forest.

Dwarf mistletoe infection was recorded as none, light, moderate, or heavy. "Light" indicated less than one-third of the trees in the stand's predominant size class were infected; "moderate" indicated one-third to two-thirds were infected; and "heavy" indicated that greater than two-thirds of the trees were infected. The stands were evaluated to a depth of 1 chain from the road for mature stands, and one-half chain in pole, and seedling stands. The percent area of lodgepole pine type affected by mistletoe was estimated by determing the ratio of miles of lodgepole pine type with infected trees present to the total number of miles of lodgepole pine type traversed.

The second part of the survey consisted of establishing variable-radius plots at three-mile intervals along the road. Plots were located 2 chains into the forest at right-angles to the road being traveled.

Plots were established on the right-hand side of the road; however, if the plot was non-type, then the left side of the road was used. If both sides were non-type, the plot location was rejected without replacement.

Basal area was determined for 107 variable plots. Diameter at breast height (DBH), and a dwarf mistletoe rating (DMR), were recorded for each tree 5 inches or more in diameter. A one-one hundredth-acre (1/100) fixed plot was also established to evaluate reproduction. Trees greater than 6 feet in height and less than 5 inches DBH were recorded and evaluated for dwarf mistletoe. Plot data were combined to represent approximately 70 hypothetical stands.

The RMYLD simulation model (Edminster 1977) was then used to estimate cubic-foot volume loss for each stand, based on the average dwarf mistletoe rating from the plots combined to make up the stand. This loss estimate was derived by making two consecutive computer runs using the model, the first with average DMR's derived from the data, and the second with all DMR's converted to zero to represent non-infected stands. The latter simulates growth over the next ten-year period as if no dwarf mistletoe infection existed in the forest.

Timber Inventory

Ninety-two Stage I timber inventory plots had been established within the lodgepole pine type in the Medicine Bow National Forest. Region 2 timber inventory personnel provided a summary of the green stand data for these plots. From printouts, data for the following parameters were transposed to a summary sheet and were segregated by computer into the following categories:

Site index (five categories)

a. 40-49
b. 50-59
c. 60-69
d. 70-79
e. $\geq$ 80

Dwarf mistletoe infection level (four categories)

a. no infection (0)
b. light (L) 1-60 percent of trees infected
c. moderate (M) 61-81 percent of trees infected
d. heavy (H) greater than 81 percent of trees infected

Basal area (five categories)

a. 0-50 ft.^{2}
b. 51-100 ft.^{2}
c. 101-150 ft.^{2}
d. 151-200 ft.^{2}
e. greater than 200 ft.^{2}

On the basis of these categories, similar plot data were segregated into 65 hypothetical stands. The RMYLD simulator was used to estimate growth loss in the same way as it was used for the survey.

Volume Loss Estimates

Incidence, as used in this paper, refers to the presence or absence of the pathogen on the timber inventory or survey plot, and does not reflect an evaluation of disease severity. Table 1 compares incidence data for the Medicine Bow National Forest acquired from several sources, revealing that 47% of the Stage I timber inventory plots contained one or more mistletoe infected trees. Fifty-five percent of the lodgepole pine acreage represented by those plots contained mistletoe infected trees. The road survey conducted in 1977 revealed that 60.5 percent of the miles traversed were adjacent to mistletoe infested stands. Sixty percent of the plots established in conjunction with the road survey contained mistletoe infected trees. Hawksworth's survey conducted in the mid-1950's reported that 59 percent of the plots on the Medicine Bow National Forest contained mistletoe infected trees.

The average volume derived from the Stage I timber inventory was 2302 cubic feet per acre (table 1). The 1977 road survey estimate was 2213 cubic feet per acre. These two estimates are not significantly different.

All data sources produced similar estimates of dwarf mistletoe incidence, and the plot portion of the road survey and the Stage I timber inventory produced comparable estimates of average total cubic foot volume per acre.

A large discrepancy occurred in the acreage and corresponding volume loss estimates for the different dwarf mistletoe severity categories (table 2). The survey conducted by trained forest pathologists resulted in a larger number of acres within the higher severity categories of infection and a concomitant increase in volume loss.

These results indicate that while timber inventory crews may be able to recognize dwarf mistletoe incidence on inventory plots, as

Table 1--Incidence of dwarf mistletoe on the Medicine Bow National Forest.

Source	Parameter	Percent
Timber Inv.	plots with mistletoe	47.0
Timber Inv.	acres with mistletoe	55.0
1977 Survey	miles with mistletoe	60.5
1977 Survey	plots with mistletoe	60.0
Hawksworth's 1958 Survey	plots with mistletoe	59.0

Per Acre Volume Estimates:

T.I. Stage I	2302.6 cu. ft.
Road Survey Plots	2213.3 cu. ft.

revealed by the consistency of the results shown in table 1, they significantly underestimate the intensity of the infection. This is further illustrated by the fact that 34 percent of the acreage was represented by average dwarf mistletoe ratings of 3.1 or greater for the 1977 survey plot data, while, according to the timber inventory data, only 3 percent of the acreage contained stands that had average dwarf mistletoe ratings greater than 3.1.

Prescott National Forest, Arizona

Other approaches to the generation of loss data were attempted for the Prescott National Forest, Arizona, by using timber inventory files and a 1970 dwarf mistletoe survey conducted by the forest. The survey was conducted in areas shown by an earlier compartment examination to contain dwarf mistletoe infected trees.

Timber Inventory Data

Dwarf mistletoe presence on plot trees was not recorded separately in the Forest Service Region 3 timber inventory as it was in Region 2; however, it was given precedence over all other damaging agents in the evaluation. If a tree displayed symptoms or signs of more than one damaging agent, one of which was dwarf mistletoe, it was recorded as mistletoe infected in the "most damaging agent" column of the inventory.

Therefore, all individual tree entries for ponderosa pine on the Prescott National Forest that did not display a dwarf mistletoe infection rating (1-6) indicated either no mistletoe or some other damaging agent category.

Dwarf mistletoe infection rating, net volume and net growth per acre in cubic feet for each plot tree, and the plot basal area and site index for approximately 130 plots were summarized for the entire forest. Total volume per acre for the average plot tree was averaged by site class for all plots with infected trees present. The same calculation was made by site class for all plots without infected trees present. The difference between these two figures (table 3) should represent the net difference in volume or growth of the average plot tree for that particular site class. Our assumption was that volume difference resulted primarily from mistletoe presence.

Data acquired from the Prescott National Forest timber inventory show that the only significant difference occurred in the volume of the average Site 1 plot tree (table 3). Net volume was significantly lower for Site 1 plots containing infected trees. Significant differences were expected for Sites II and III, but were not detected. No significant differences were observed when all plots, irrespective of site, were combined; again, significant differences were expected but did not occur.

Although significance was noted for the one category, our confidence in the results is low and will remain so until they are verified. It is possible that site evaluation was compromised in the inventory as a result of using the height of dwarf mistletoe infected trees to establish site. The most we could possibly infer from these data is that dwarf mistletoe seems to be lowering the productivity of those areas with good growth potential.

Table 2--Annual cubic-foot volume loss estimates for the Medicine Bow National Forest, derived from Stage I Timber Inventory and 1977 plot surveys using RMYLD model.

Dwarf Mistletoe Severity Category	M's of Acres Represented		Annual Cubic Foot Volume Loss	
	Stage I Tim. I.	1977 Plot Survey	Stage I Tim. I.	1977 Plot Survey
0	158	182	0	0
0.1-1.0	138	38	0	0
1.1-2.0	37	17	20,780	7,015
2.1-3.0	12	10	72,857	56,087
3.1-4.0	4	47	49,776	871,891
4.1-5.0	4	60	17,880	2,879,211
5.1-6.0	-	21	-	194,044
TOTAL	353	375	161,300	4,008,250

Dwarf Mistletoe Survey

A second source of information on dwarf mistletoe-caused loss for the ponderosa pine type on the Prescott National Forest was available from a dwarf mistletoe survey conducted during 1969 and 1970. The original data from this survey were furnished to Forest Insect and Disease Management (FI&DM) personnel by the Forest. Region 3 FI&DM personnel summarized these data, extracting the following parameters:

A. Dwarf Mistletoe Level (DMR)

1. (0) = no infection
2. (1-2) = low
3. (3-4) = moderate
4. (5-6) = heavy

B. Size Class (As defined in the original dwarf mistletoe survey, 1972)

1. 1 to 7 in.
2. 7.1 to 11.6 in.
3. Greater than 11.6 in.

C. Site Class (Region 3 uses three categories, as follows)

1. Site 1: greater than 75
2. Site 2: 55-74
3. Site 3: 54 or less

D. Basal Area

Basal areas were used to describe stand density and calculate the DBH of the tree of average basal area, parameters necessary to use with the RMYLD simulator.

Height was not available from the dwarf mistletoe survey data; however, the RMYLD simulator will insert a standard value for height if site is given.

The combined results of two separate complete runs using the RMYLD simulation model show that the annual cubic-foot volume loss estimates generated for the overstory and understory were 37,000 and 46,200, respectively (table 4). These losses occurred on approximately 6000 of 9300 infested acres. Dwarf mistletoe was present, but losses were not projected for approximately 3300 acres.

Deschutes National Forest, Oregon

A third approach to determine loss on a Forest-basis is being attempted for the Deschutes National Forest, Oregon. For this Forest, we will estimate cubic-foot volume loss using growth parameters from existing inventory data.

Table 3--Cubic-foot net growth and net volume per acre for the average plot tree[1] in dwarf mistletoe non-infested and infested plots from the Prescott National Forest.

		Non-infested plots[2]	Infested plots[3]	Difference
NET GROWTH	Site I	1.8	1.7	0.1
	Site II	1.4	1.8	-0.4
	Site III	1.1	1.1	0.0
NET VOLUME	Site I	72.7	59.3	13.4**
	Site II	62.0	56.3	5.7
	Site III	48.1	50.9	-2.8

[1] Ponderosa pine only

[2] Column derived from 72 plots

[3] Column derived from 21 plots

** Statistically significant at 1 percent level

Region 6 timber management personnel will search timber inventory tapes for the Deschutes National Forest, and retrieve and record the following 10 parameters for each tree entry:

1. Plot number
2. Site class
3. Net growth in cubic feet
4. Diameter at breast height
5. Height (site trees only)
6. Age
7. Crown class
8. Dwarf mistletoe rating
9. Tree history
10. Condition class

Net growth recorded on the forest's data tape is a derived entry. Actual observed net growth for plot trees is available only from the original field data cards on the first three points of a 10-point cluster plot. These data entries have been retrieved by hand, and will be appended to the newly-produced data tape file.

Volume loss estimates will be made in two ways. The first will provide estimates for hypothetical stands by site class and dwarf mistletoe rating using actual measured net volume growth as the dependent variable. The total number of entries used for this summary will be approximately 30 percent of the total number of ponderosa pine trees sampled during the inventory. Since future estimates cannot rely on the manual transposition of field records for data input, the second estimate of growth loss volume will come directly from the Forest's plot summaries. These will consist of net growth for each plot by site and by average plot DMR using all individual tree entries. Growth loss estimates, derived in these two ways, will then be compared to determine the reliability of the latter method.

REVISED APPROACH TO GATHERING INFORMATION

The Dwarf Mistletoe Loss Assessment Working Group met again in January 1978, reviewed the results reported in this paper, and made several changes in our approach to loss assessment.

The Group still was committed to the belief that Forest Inventory and Forest Survey systems remain the only feasible way to collect and store certain insect- and disease-caused loss information applicable over large areas. However, our approach to gathering interim data has changed. We are requesting that each Region update estimates that were made in 1975. Many Regions have recent data that should improve the reliability of their 1975 estimate. Other Regions plan to use the road survey procedures previously discussed to add to their data base. Other sources may be consulted.

The Forest Survey unit of the Pacific Northwest Forest and Range Experiment Station is presently working with dwarf mistletoe incidence data for state and private lands in Washington and Oregon. This information has been summarized at this Symposium. Data were

Table 4--Cubic-foot volume loss derived from the RMYLD simulator using 1970 dwarf mistletoe data from the Prescott National Forest.

Infested Acres	Cubic-foot volume loss overstory	understory	total
3322	0	0	0
5984	37,000	46,200	83,200
9306	37,000	46,200	83,200

collected using Hawksworth's rating system. When they have completed their summary work, specialists in Regions 5 and 6 can use the incidence data to estimate volume loss.

Region 5 FI&DM personnel recently collected dwarf mistletoe incidence data for the San Bernardino National Forest as part of the Pest Damage Inventory (PDI). These supplemental data were collected to determine whether or not the RMYLD simulator could be used in southern California. Other data from the Pacific Southwest Forest and Range Experiment Station will be consulted to determine how suitable they are for making volume loss estimates for Region 5.

The diverse methods and data sources being used to make interim loss estimates illustrates the inconsistency in existing data from area to area. The diversity of approaches points out the need to incorporate more complete insect and disease information in the regional timber inventory systems and Forest Survey wherever possible. The Dwarf Mistletoe Loss Assessment Working Group still believes that the timber inventory data base is the logical place to maintain data on insects and pathogens which influence forest productivity. The data would be beneficial to most administrative levels, from the timber manager on the Ranger District to the U.S. Office of Management and Budget in Washington, D.C. This approach would require greater commitment by FI&DM personnel to training timber inventory crews, possibly even providing one well-trained individual per crew for the insect and disease recognition portion of the inventory. This person need not be a professional, but could be a technician thoroughly trained in insect and disease recognition.

LITERATURE CITED

Baranyay, J.A., and L. Safranyik.
1970. Effect of dwarf mistletoe on growth and mortality of lodgepole pine in Alberta. Can. Dep. Fish and Forest. Publ. 1285, 19 p.

Edminster, C.B.
1977. Computation of yield tables for even-aged and two-storied stands. USDA Forest Serv. Res. Paper. Rocky Mountain Forest and Range Exp. Stn., Ft. Collins, Colo.

Hawksworth, F.G.
1958. Survey of lodgepole pine dwarf mistletoe on the Roosevelt, Medicine Bow, and Bighorn National Forests. Rocky Mountain Forest and Range Exp. Stn. Paper 35, 13 p.

Hawksworth, F.G.
1956. Upper altitudinal limits of dwarf mistletoe on lodgepole pine in the central Rocky Mountains. Phytopathology 46:561-562.

Hawksworth, F.G., and T.E. Hinds.
1964. Effects of dwarfmistletoe on immature lodgepole pine stands in Colorado. J. For. 62:27-32.

Weir, J.R.
1916. Mistletoe injury to conifers in the Northwest. U.S. Dep. Agric., Agric. Bull. 360, 39 p.

IMPACT EVALUATION FOR DWARF MISTLETOE-INFESTED PONDEROSA PINE IN THE SOUTHWEST[1]

James W. Walters[2]

Abstract: Southwestern dwarf mistletoe (Arceuthobium vaginatum subsp. cryptopodum) occurs on more than one-third of the commercial ponderosa pine forest in Arizona and New Mexico. Annual volume loss from this disease is estimated at 150-200 million board feet on National Forests in the Southwestern Region. The simulated yield program SWYLD2 is used to help evaluate impact of southwestern dwarf mistletoe. A survey procedure and data summary program have been designed to compile input for the SWYLD2 program. This program provides resource managers with simulated yield tables for dwarf mistletoe-infested stands of ponderosa pine. Yield tables help quantify timber volume loss, and allow resource managers to examine various management alternatives and their effects on dwarf mistletoe levels.

Southwestern dwarf mistletoe (Arceuthobium vaginatum subsp. cryptopodum) is the most destructive disease on ponderosa pine in the Southwest. This disease occurs on all National Forests in Arizona and New Mexico. Andrews and Daniels (1960) calculated southwestern dwarf mistletoe to be present on at least 2.5 million acres of commercial ponderosa pine forest in Arizona and New Mexico. Annual volume loss from this disease is estimated to exceed half of the annual allowable cut on National Forests in Region 3. Principal hosts for southwestern dwarf mistletoe include ponderosa pine, Pinus ponderosa var. scopulorum, P. ponderosa var. arizonica, and Apache pine, P. engelmannii. The adverse effects of southwestern dwarf mistletoe have been quantified in several ways. Mortality estimates have been made for infested stands, potential safety hazard in recreation areas has been evaluated, and timber volume loss has been quantified on a stand basis. The latter is perhaps the most useful tool for evaluating dwarf mistletoe effects over large areas.

Three factors contribute to timber volume loss: growth reduction, tree mortality, and defect. Growth reduction is the most important and most difficult value to estimate. Heavily-infected trees may sustain a 30-60 percent growth reduction, compared to non-infected trees. The amount of reduction depends on time and intensity of infection, tree size and age, site factors, and many other aspects of tree environment.

Tree mortality is the second most important volume loss factor. Mistletoe-caused mortality can be difficult to quantify due to invasion of infected trees by insects. Assigning the primary mortality factor often becomes impractical. Andrews and Daniels (1960) estimated annual mortality losses in mistletoe-infested ponderosa pine at 55-75 million board feet in the Southwest.

Defect caused by dwarf mistletoe is related to grain distortion and resin impregnation at infection sites. This aspect of volume loss is seldom measured, and its overall importance is not well-defined for Southwestern forests.

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[1] Presented at the Symposium on Dwarf Mistletoe Control Through Forest Management, Berkeley, Calif. April 11-13, 1978.

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Commonly used evaluation techniques, such as measurement of volume loss, frequently estimate only one of the many effects resulting from a dwarf mistletoe infestation. For example, expressing adverse effects of dwarf mistletoe in terms of cubic foot loss per acre emphasizes the timber production aspect. It becomes more difficult to apply cubic foot loss to deterioration of wildlife habitat, recreational opportunity, or watershed productivity. In fact, what is an adverse effect on one resource may be beneficial to other resources. When a disease such as dwarf mistletoe alters the forest environment, questions must be answered to determine the total effects on all resources and resource users. These effects, when identified and quantified, constitute the impact of a forest disease. Can we measure this complex of effects? Do we have the expertise to evaluate such a vast array of factors? What terminology do we use to express positive and negative effects? These questions must be answered before impact evaluation can be realized.

There may be some confusion about who has responsibility for impact evaluation of dwarf mistletoe. In the U. S. Forest Service, personnel in Forest Insect and Disease Management cooperate with designated National Forest System personnel to develop impact data on dwarf mistletoe. In the Southwest, a forest disease specialist provides an assessment of the effects dwarf mistletoe is and will be having on infested stands (biological evaluation). This information is provided to the resource manager, so that, jointly, an impact evaluation can be prepared. Resource managers call on other specialists to help evaluate impact of dwarf mistletoe on other resources. In essence, a team of specialists provides input to the resource manager relative to mistletoe effects and their area of specialization. The resource manager then combines this information and completes the impact evaluation. An important factor to note is that we, in Forest Insect and Disease Management, really do not evaluate impact of a forest disease per se. We evaluate the current status of a disease, quantify certain effects of that disease, project the disease situation into the future, whenever possible, and assess or recommend potential control measures.

More finitely, in relation to southwestern dwarf mistletoe, we most frequently estimate only timber volume loss in an infested stand. This quantity then, constitutes our major input in the impact evaluation process.

Dwarf mistletoe evaluation efforts in the Southwest have been concentrated in high priority resource areas. Such areas are characterized by high-timber production potential (i.e., site index and accessibility) high-value recreational opportunity, or areas of special interest to resource managers (i.e., difficult regeneration areas). Economics define these types of areas as locations where adverse effects of dwarf mistletoe can be efficiently reduced. If a resource manager does not have sufficient funds to control dwarf mistletoe, there is little benefit in quantifying those effects. Exceptions occur in areas where quantifying disease effects can alter priorities (i.e., dollars and personnel). Eventually, we hope to participate in evaluating impact for all dwarf mistletoe-infested stands, but a system of priorities must be followed to obtain maximum benefit from our efforts.

Current Region 3 evaluations of southwestern dwarf mistletoe use the simulated yield program SWYLD2 (Myers et al. 1976, Edminster and Hawksworth 1976). This program provides resource managers with simulated yield tables for dwarf mistletoe-infested stands of ponderosa pine. Yield tables help quantify timber volume loss caused by dwarf mistletoe. Resource managers can examine various management alternatives and their effects on dwarf mistletoe levels. In addition, they can better evaluate the benefits and consequences of controlling dwarf mistletoe.

Application of the SWYLD2 program is restricted to even-aged or two-storied stands that are at least 90 percent ponderosa pine. Stands not meeting these requirements are not necessarily precluded from the mistletoe evaluation process, but our assessment lacks the predictive aspect.

Basic input in the SWYLD2 program is relatively uncomplicated. Stand condition variables needed for SWYLD2 input include: site index, average age, height and d.b.h., number of trees per acre, and stand DMR or percent trees infected with dwarf mistletoe. Stand DMR is the average dwarf mistletoe rating, based on the six class system, for all trees in a stand. These values must be provided for both stories in a two-storied stand. We have designed a survey procedure for gathering this information in even-aged or two-storied ponderosa pine stands.

Sample points are located on a grid throughout the survey area. Grid interval varies with stand size. A 4- by 4-chain grid may be used in a 200-acre stand, while a 10- by 10-chain grid may be selected for use in a 1,000-acre area. Fixed and variable radius plots (B.A.F.) are established at each sample point. The sample consists of all live trees 4.5 feet tall to 5.9 inches d.b.h. on the fixed plot, and live tally trees 6.0 inches d.b.h.

and larger on the B.A.F. plot. Presence/absence of dwarf mistletoe or dwarf mistletoe rating (DMR) and d.b.h. are recorded for all sample trees. A sketch map of plot locations is made during the survey for later use in showing dwarf mistletoe distribution. A specified number of age and height measurements are taken to estimate site index. Age and height measurements are also taken from a specified number of codominant or dominant trees in each story of the stand. Data are recorded on forms specifically designed for rapid transfer of information into a computer summary program.

Field data are then processed through the SWSUMMARY computer program. This program was designed to accommodate data from the previously outlined survey. SWSUMMARY prepares stand summary tables and calculates SWYLD2 stand condition variables from survey data. The program also summarizes age and height information for three sets of selected trees. These selected trees represent (1) maximum site potential of the stand, (2) average age and height of overstory dominant and codominant trees, and (3) average age and height of understory "dominant" and "codominant" trees. The summary tables provide a stand inventory and are useful in determining SWYLD2 management options.

Resource managers develop various management options and combine them with stand condition variables to produce simulated yield tables. Comparison of various management alternatives helps the resource manager quantify effects of dwarf mistletoe in an infested stand.

A cost analysis was made for eight survey areas completed in 1977. A 10- by 10-chain grid was used for all surveys. Cost estimates are based on field crew of two forestry technicians (i.e., $4/hr./technician) working 40 hours per week. Average cost, including travel time from Ranger District office to survey area, was 30¢ per acre. Pure survey cost, excluding travel to the survey area, averaged 23¢ per acre. Reducing the grid interval from 10- by 10-chains to a closer spacing will increase survey cost. However, we estimate that even at a 4-chain interval, survey cost will not exceed 75¢ per acre. The range in survey cost from 23¢ to 75¢ per acre appears reasonable for use of an intensive forest management tool.

Once the resource manager has a set of yield tables displaying volume loss caused by dwarf mistletoe over a rotation, various degrees of control can be simulated. Management alternatives which best meet the resource manager's needs can then be selected for implementation. SWYLD2 output is expressed in total cubic foot volume, merchantable cubic foot volume, and board foot volume on a per-acre basis. These values can be converted into dollar estimates by each individual resource manager. Individual conversion to dollar values is essential as market values vary with accessibility to production facilities, access to a labor force, etc. Once loss estimates are converted from cubic or board foot volume to dollar value, resource managers can determine the cost of dwarf mistletoe control; then, a cost/benefit ratio can be determined. Often, impact on other resource values can be quantified and compared with mistletoe control costs at various management intensities.

The final step in the evaluation process deals with follow-up on mistletoe evaluations. When a resource manager implements a silvicultural treatment, as projected by the SWYLD2 program, Forest Insect and Disease Management personnel may resurvey the stand. Follow-up survey data provide an assessment of how well simulated stand conditions match on-the-ground conditions. When actual conditions do not match those projected, an attempt is made to determine where the discrepancy occurred. In addition, simulations are made for the residual stand after treatment. Thus, the resource manager has an opportunity to correct inadequate treatments and to reassess the dwarf mistletoe situation for future years. This, in turn, provides more finite information for future timber management planning.

Through this follow-up procedure, for instance, we have found that maximum diameter limits and/or spacing restrictions in precommercial thinnings result in poor mistletoe control. These factors also can make simulation of such treatments less reliable. Such information is valuable to the resource manager who has based an impact evaluation on SWYLD2 projections.

As forest management continues to intensify, use of simulated yield programs will increase. Yield simulations, such as those provided by the SWYLD2 program, will continue to help the resource manager evaluate the impact of a forest disease such as southwestern dwarf mistletoe.

Dwarf mistletoe poses an unquestionable threat to the potential of forest resource production in the Southwest. Various techniques have been used to quantify the magnitude of this threat. Of the techniques used, summarizing timber volume loss over a designated time period appears to be the most efficient. The simulated yield program SWYLD2 has provided the methodology to complete this task. Resource managers can now begin to assess, in a more finite manner, the overall effects of dwarf mistletoe on all resources. Thus, the capability to evaluate impact of southwestern dwarf mistletoe is in the final development stages.

LITERATURE CITED

Andrews, S. R., and J. P. Daniels.
1960. A survey of dwarfmistletoe in Arizona and New Mexico. U. S. Dep. Agric., For. Serv., Rocky Mt. For. and Range Exp. Stn., Stn. Pap. 49. 17 p.

Edminster, C. B., and F. G. Hawksworth.
1976. User's guide to SWYLD2: Yield tables for even-aged and two-storied stands of southwestern ponderosa pine, including effects of dwarf mistletoe. U. S. Dep. Agric., For. Serv. Gen. Tech. Rep. RM-23. 8 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colorado.

Myers, C. A., C. B. Edminster, and F. G. Hawksworth.
1976. SWYLD2: Yield tables for even-aged and two-storied stands of southwestern ponderosa pine, including effects of dwarf mistletoe. U. S. Dep. Agric., For. Serv. Res. Pap. RM-163. 25 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colorado.

Control Operations and Accomplishments

INTRODUCTION TO DWARF MISTLETOE CONTROL[1]

Lewis F. Roth[2]

ABSTRACT

Dwarf mistletoes are parasitic, destructive and economically damaging in the coniferous forests where they occur. Timber volumes of native forests infected with dwarf mistletoes are lower than are timber volumes in healthy forests of the same age. In the past, human activities in the forests--such as logging and fire control measures--actually encouraged the spread of the mistletoes. Positive steps toward control of dwarf mistletoe must now be taken or future stands will suffer even more acutely than those of the contemporary forests. Differences in climate and in distribution of hosts, site quality, and stand structure are known, natural limitations to spread of infection. Most dwarf mistletoe plants are visible so that boundaries of disease occurrence are easily observed, and development of the parasite in space and time is now well understood. After evaluating form and extent of damage, forest managers should plan appropriate strategies to contain dwarf mistletoe spread well within the critical threshold of infection. Because fire can influence shifting population balances in forest communities, it may become a tool for dwarf mistletoe control. In addition, resistance to dwarf mistletoe will be raised as a secondary benefit of silvicultural treatment through selection of better crop trees.

Dwarf-mistletoes are indigenous members of many coniferous forest communities. Dwarf mistletoes are by nature parasitic and are destructive and economically damaging in the stands where they occur. Timber volumes of infected native forests have long been recognized as lower than volumes in healthy forests of the same age. This reduction of volume demonstrates above all else, a slower rate of growth of the host in the presence of the parasite. Forestry practices during the first half of the present century or longer seem to have aggravated the dwarf mistletoe problem. Fire control as well as logging practices that were poorly suited to infected stands appear especially to have been responsible. Because of this early neglect positive steps must now be taken in many infected or threatened stands to control these pests. If they are not taken, young and future stands will suffer even more acutely than the contemporary forest.

While sometimes perplexing, dwarf mistletoes should not seem as mysterious to the forester as are diseases caused by widely and erratically distributed microscopic fungus spores, or by invisible environmental causes. Though some dwarf mistletoe plants are in fact not visible most may be readily seen, and disease symptoms often are striking. This visibility enables recognition of boundaries of disease occurrence in the forest, even by observers with limited experience and training, and allows fairly accurate evaluation of levels of severity, both current and anticipated. Mystery, therefore, should not be an obstacle preventing the manager from undertaking dwarf mistletoe control. However, earlier speakers have shown that a fairly sophisticated knowledge of mistletoe parasitism and of stand development in the presence of the parasite is required.

The fact that our indigenous coniferous forest produced timber of unexcelled quality and quantity demonstrates that these forests comprised ecosystems that were biologically stable and were in balance with their physical environment. This is good evidence that destructive disease outbreaks occurring today necessarily must have originated from disturbing human activities in the forest. The most important of these disturbances appear to be: first, stand modifications accompanying logging, which were forced upon the forest and often conducted with indifference or lack of understanding; second, introduction of exotic pathogens; and finally, fire control. It is logical, therefore, to look to contemporary human activity in the forest for many of the specifics that have caused dwarf mistletoe to increase, and for solutions to the problem as well.

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[1] Presented at the Symposium of Dwarf Mistletoe Control Through Forest Management, Berkeley, Calif., April 11-13, 1978.

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Since the dwarf mistletoes are not exotics we can turn directly to interactions among components of the natural forest communities and their environment for control strategy. Absence of adequate resistance of the host necessitates that either we destroy the sources of inoculum by exterminating the pest from production units or alternatively that we manage our relatively susceptible hosts by special procedures in the presence of the pathogen. Both options may be employed in a well rounded control program.

Dwarf mistletoes develop in a context of space and time that is now reasonably well understood. There have been real natural limitations on mistletoe development. These limitations are evident from the fact that the parasite does not occur throughout the Western coniferous forest type or throughout any particular forest and it does not wholly destroy any infected stand. The limitations appear to be more physical than biological in as much as the fossil record shows the parasite to have been present for a long time without the evolution of reasonably effective genetic resistance in the host. Differences in climate and in distribution of hosts appear predominant in limiting general occurrence of the pests. Site quality greatly influences local severity. Fire limits both local severity and distribution, and stand structure especially influences damage within the stand.

The form and extent of damage must be evaluated at appropriate management levels: industry or agency, forest, timber stand and unit, before policy decisions to undertake control - perhaps at any level - can be soundly made. While dwarf mistletoe is rather easily detected, evaluation of damage is complicated and sometimes is so difficult as to be debatable among qualified professionals. Evaluation must first consider the existence and extent of damage - not just the presence of the parasite - and should then determine whether the disease trend, in the absence of control, is toward increased severity or toward improvement. If it is not toward improvement, decisions will be required as to: 1) levels of control that are intended or are acceptable (this can range from complete control to none); 2) feasibility of the undertaking; and 3) costs; and probable benefits. While these decisions are subject to economic considerations, long term management objectives, and utilization opportunities, the pathoglogist's attention is directed primarily toward the effect of mistletoe on stand productivity.

Most past practice was directed toward destruction of the mistletoe plants themselves, usually within supernumerary trees of the current crop. Limitation of lateral spread of the pathogen and reduction of growth loss within infected stands now appear to be more appropriate primary control objectives, with eradication to follow in subsequent rotations.

In most undisturbed stands, as indicated earlier in the symposium, manifestation of dwarf mistletoe in the forest is in, or near, a delicate state of equilibrium whether measured by size of plants, number of plants or damage to the host. This equilibrium is highly dependent on site and other features influencing host growth. Pure stands such as ponderosa pine on very poor sites may stagnate indefinitely when infected and may be unresponsive to treatment. Contrarily, on superior sites infected stands appear to be capable of sustained production at or near site capacity without special management attention.

Stands that are intermediate between the extremes of damage are of greatest concern for the forester because of their potential, on one hand, to become worse and, on the other, because of the control opportunities they afford. The exact thresholds of infection at which the pest can be made harmless or, if not harmless, then manageable, depend on site quality and other growth opportunities. These thresholds are unlikely to be constant. Whatever the circumstances, dwarf mistletoe control procedures should be such that the stands stay well on the safe side of the critical thresholds. If excessively damaged stands are treated, benefits are likely to be short term. Treatment probably should be applied only at a stage of stand development when a single treatment will improve growth enough to carry the stand to merchantable size. Younger stands on poorer sites probably should be destroyed and the sites sanitized and regenerated.

Mistletoe control procedures applicable to pure stands are limited primarily to tree spacing and the removal of heavily infected trees or branches. However, where site and other considerations are suited to more than one tree species, new control opportunities arise. Dwarf mistletoes tend to be host specific. If growth and production conditions allow, balance within the disease system may be swung away from the parasite by altering stand composition or, if necessary, converting to an alternative species. Deliberate changes of species on the margins of infested areas provide effective barriers to further lateral spread of the parasite.

Fire has long been an influence in shifting population balances in forest communities and has had an important historical effect on dwarf mistletoe. Fire may offer much as a tool for control when its use in forest management is more completely investigated.

Many years of observation of the diversity shown by western dwarf mistletoe on ponderosa pine have led me to believe that a genetically broad base of horizontal resistance to dwarf mistletoe exists. While resistance has been badly eroded in the past by fires that destroyed progeny naturally selected for resistance, I believe that the level of horizontal resistance will be raised as a secondary benefit of silvicultural treatment through selection of better crop trees. Further improvement of the genetic tool for dwarf mistletoe control can be made by the tree breeder.

Whatever approaches to dwarf mistletoe control may be undertaken, I expect that none will succeed without a thorough understanding of both dwarf mistletoe dynamics and manipulation of forest stands. This knowledge is to be gained from our panel.

GENETIC CONTROL OF DWARF MISTLETOE[1/]

Lewis F. Roth[2/]

ABSTRACT

Trees in natural ecosystems in the course of their evolution have acquired less resistance to dwarf mistletoes than to many other native diseases. Nevertheless trees do resist mistletoe by: 1) taxonomic resistance, as a consequence of evolution, 2) single gene, vertical resistance, 3) polygenic horizontal resistance and 4) escape by means of heritable structural characteristics. Silvicultural control by change of species is based on taxonomic resistance. Practices include: selective treatment in mixed stands, special regeneration procedures, underplanting of shelterwoods, or establishment of non-host barriers to spread. In the absence of vertical resistance silvicultural control often is achieved at the price of reduced productivity. The silvicultural objectives can be met to a degree by horizontal resistance. Existing horizontal resistance can be further strengthened by silvicultural improvement of infected stands. Consequently genetic control of dwarf mistletoe is immediately available.

Genetically based resistance to infection resulting from co-evolution of forest trees and their pathogens has been the chief means of disease control in natural ecosystems (Van der Plank 1975). Serious disease outbreaks are absent from the forest except when the environment fluctuates widely or is artifically modified; or when introduction of either foreign hosts or pathogens occurs. Contrarily, the native dwarf mistletoes are regularly destructive in natural forests. Consequently they are properly regarded as exceptions. However, their dominance over their hosts is only partial and genetic resistance is a potential tool for their control. It is appropriate therefore to ask why so little attention has been given to genetic control and to consider future prospects.

Genetically based features have been used by forest managers, for control of dwarf mistletoe far more extensively than is generally realized. At the same time genetic resistance has been inadvertently, if not intentionally, ignored in tree improvement programs. The assumption used to justify this omission has been that the whole mistletoe control requirement can be expeditiously met by silvicultural treatment.

Although silvicultural methods are likely to dominate the control effort it will be well to examine our silvicultural practices more analytically and to broaden our concept of genetic control as these practices concern management of the dwarf mistletoe problem.

Trees resist damage by dwarf mistletoe in four genetically related ways: 1) by immunity accompanying co-evolution of the Pinaceae and Arceuthobium during, perhaps, the last 20 million years, 2) by vertical resistance (possession of specific resistant genes that match mistletoe genes for pathogenesis) (Van der Plank 1975), 3) by horizontal resistance (possession of polygenically regulated factors which in the aggregate suppress infection and limit disease (Robinson 1976) and 4) by disease escape based on heritable characters.

In spite of its great potential, vertical resistance is our least used genetic tool. This is partly because of challenging technical difficulties, including the necessary painfully slow conventional breeding methods that have discouraged its development. It is unfortunate that the historical dominance of single gene (vertical) resistance in the thinking of forest scientists should, for so long, have obscured other opportunities for mistletoe control by genetic means.

Immunity to plant disease is regarded by some (Robinson 1976) to be the rule rather than the exception. The form of immunity most often encountered by the dwarf mistletoes has developed during the course of evolution

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[1/] Presented at the Symposium on Dwarf Mistletoe Control Through Forest Management, Berkeley, Calif. April 11-13, 1978.

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accompanying host speciation (Hawksworth and Weins 1972). It is expressed in the inability of one mistletoe, A. douglasii Engelm. on Douglas-fir for example, to attack another conifer such as ponderosa pine, when the two trees grow together in a mixed stand. Host immunity to the dwarf mistletoes is not absolute.

One tree species occasionally may be parasitized by a mistletoe having another tree species as its principal host. Thus secondary hosts occur which, though infected, usually cannot alone sustain the mistletoe population. Larch mistletoe (A. laricis [Piper] St. John) for example, may occur on white firs, mountain hemlock, lodgepole and ponderosa pines, Engelman spruce and white pines, but never in damaging amounts in the absence of the principle host, western larch.

Single gene resistance to dwarf mistletoe probably is rare. Such resistance is known against an endemic leaf pathogen, Didymascella thujina in western red cedar (Soegaard 1964). Hypersensitive reaction (sudden death of cells at the point of host penetration) which is commonly regarded as an indicator of single gene resistance, has been observed with dwarf mistletoe on ponderosa pine by Roth and Adams (unpublished data). Roth (1966) pointed out that survival of young ponderosa pine selected out of the existing gene pool as resistant to A. campylopodum is almost impossible under forest circumstances favorable for selection. The high flammability of the heavily infected stands where selection is progressing has made them particularly vulnerable to destruction by fire. Host species of other mistletoes may fare better.

If single gene resistance occurs, nothing is known of its heritability and hence little of its usability. Horizontal resistance seems more likely to occur because it can develop in the absence of selection pressure. It can also arise from a wide range of gene combinations so is likely to be more immediately usable.

Discovery of trees that are good candidates for resistance is difficult because so many forest influences determine whether a tree will be infected. Among non-genetic factors are tree size, characteristics of the inoculum source and, position of the suscept tree in the stand. Nevertheless, considerable resistance occurs among some individuals in natural stands even though all stands are so susceptible, as communities, as to require protection or control in the presence of the parasite. This resistance of individuals is horizontal resistance. It is seen, for example, in grafts of 40 to 50 ponderosa pines selected and tested under field conditions. These trees have remained mostly mistletoe free during 10 or more years (23 for 7 trees) of testing (Roth, unpublished data, Roth 1974a). Occasional mistletoe plants have appeared over the years on most of the "parent" trees. However, one notable parent has stood in the annual mistletoe seed shower from a heavily infected, large pine for more than 100 years without becoming infected. This pine appears to be immune to pine dwarf mistletoe (A. campylopodum).

Older trees are more resistant to dwarf mistletoe than young trees (Roth 1974a). While small trees may remain practically uninfected under an infected overstory for as long as 10 years these trees should not be regarded as resistant. Their safety lies in the small target they present to the mistletoe seeds (Wicker and Shaw 1967). Large trees collect many more mistletoe seeds than small trees. If large trees remain substantially mistletoe free under conditions of high exposure they probably are exhibiting horizontal resistance at a useful level.

A further expression of horizontal resistance has been noted (Roth 1974b)in the differential ability of ponderosa pines to tolerate infection by A. campylopodum. Trees in which diseased tissue is localized because of resistance of the phloem to invasion of the endophytic (absorptive) system of the mistletoe are lightly damaged. Such trees produce short, only slightly damaging, spindleshaped swellings in the presence of the endophyte. These trees contrast sharply with those lacking resistance of the phloem. Branches on the latter are abnormally thickened with long and tapered swellings. Their tissues are extensively occupied by the endophyte. We assume them to be extensively damaged physiologically.

Disease escape is a further means of limiting dwarf mistletoe. Escape mechanisms expressed through host morphology may be directly useful to the manager during stand improvement work or indirectly in a breeding program. Drooping foliage in ponderosa pine is an example. Dwarf mistletoe seeds are intercepted by needles of the potential host and depend on rain in order to slide into stem positions on thin-barked branchlet tips favorable for infection (Roth 1959, Scharpf and Parmeter 1967). Most seeds on drooping needles are washed from the needle tips onto the ground. On good sites in southwestern Oregon where drooping needles are a predominent foliar habit, mistletoe is rare.

Geographic escape should perhaps be mentioned also. Though the respective hosts are susceptible, escape is seen, for example, in Douglas-fir dwarf mistletoe that does not significantly enter the heart of the Douglas-fir region. Similarly, southwestern dwarf mistletoe (A. vaginatum Engelm.) does not occur on ponderosa pine, its principal host, in the Pacific Northwest.

Now briefly consider applications of these relationships in forest management. Immunity accompanying speciation (taxonomic immunity) is a mainstay of silvicultural control of dwarf mistletoe. It allows reforestation with an alternate tree species when site sanitation is not possible. It enables safe underplanting of shelterwoods and is particularly valuable where the overstory must be kept for longer than 10 years (Wicker 1975). It allows plantings of alternative species around cutting units in order to establish immune border strips against infected stands. In mixed stands it allows the manager to sacrifice the severely diseased and damaged species and to carry the residual stand of alternative species to rotation age. It must be considered, however, that a mixed forest is more than the sum of its species. It is unlikely that any of the components, alone or in combination, can occupy the site to the productivity level achieved by the natural mixture, even though fully stocked. In many cases, if not in most, a trade-off in productivity will be required to accomplish the mistletoe control.

In this trade-off lies the misfortune of our failure long ago to pursue a breeding program for dwarf mistletoe control, including vertical resistance. With stock possessing high resistance, or immunity such as that of the pine mentioned earlier, all of the preceding silvicultural practices could be accomplished with no sacrifice of stand quality. Fortunately, there is a chance that objectives of some of these practices can be achieved through horizontal resistance even though of a lower level than immunity. Availability of such resistant stock might not be too distant if it were aggressively pursued.

Though it has not been experimentally demonstrated, there are indications that strong gains in horizontal resistance are made when heavily diseased young stands are treated for mistletoe control during timber stand improvement. Thinning after stands are 50 years old will have allowed most of the highly susceptible trees, during their juvenile period, to disclose their susceptibility and need for removal. By this time, also, the larger but less resistant trees will have become conspicuously infected, or will already have weakened in competition with their more resistant, less heavily infected associates and will be removed. The rate of disease development in these stands after treatment certainly will be slower than would have been the case in stands of equal stocking of the original genotypic composition at equivalent spacings.

Many stands of ponderosa pine in the Pacific Northwest treated for mistletoe in the early years of the young-growth control program should be nearing reproductive age and might quite reasonably be examined for gain in resistance if not for potential of development as seed orchards. If stands cannot be found that are suitable for orchard development, then timely steps should be taken to develop such stands.

In closing, opportunities for improved "resistance" through escape from infection should be briefly mentioned. Trees likely to escape, especially those with growth characteristics conducive to non-retention of dwarf mistletoe seed, drooping needles being perhaps the best known, can in some cases be recognized and left in the stand during thinning. Morphological features contributing to escape are appropriate material for the tree breeder. Clearly genetic considerations have a part to play now and in the future in a complete mistletoe control policy.

LITERATURE CITED

Hawksworth, F. G. and Delbert Wiens.
1972. Biology and classification of dwarf mistletoes (Arceuthobium) U.S. Dep. Agric., Agric. Handb. 401, 234 p.

Robinson. Raoul A.
1976. Plant pathosystems. 184 p. Springer-Verlag. Berlin.

Roth, Lewis F.
1959. Natural emplacement of dwarf mistletoe seed on ponderosa pine. Forest Sci. 5: 365-369.

Roth, Lewis F.
1966. Foliar habit of ponderosa pine as a heritable basis for resistance to dwarf mistletoe. pp. 221-228 *In* Gerhold, H. D. *et al.* (Eds.). Breeding Pest Resistant Trees, Permagon Press. Oxford. 505 p.

Roth, Lewis F.
1971. Dwarf mistletoe damage to small ponderosa pines. For. Sci. 17: 373-380.

Roth, Lewis F.
1974a. Juvenile susceptibility of ponderosa pine to dwarf mistletoe. Phytopathology 64: 689-692.

Roth, Lewis F.
1974b. Resistance of ponderosa pine to dwarf mistletoe. Silvae Genetica 23: 116-120.

Scharpf, R. F. and J. R. Parmeter.
1967. The biology and pathology of dwarf mistletoe, *Arceuthobium campylopodum* f. *abietinum* parasitizing true firs (*Abies* spp.) in California. U.S. Dep. Agric. Tech. Bull. 1362. 42 p.

Soegaard, Bent.
1964. Variation and Inheritance of Resistance to attack by *Didymascella thujina* in Western Red Cedar and Related Species. pp. 83-88. *In* Gerhold, H. D. *et al.* (Eds.) Breeding Pest Resistant Trees. Permagon Press. Oxford. 505 p.

Van der Plank, J. E.
1975. Principles of Plant Infection. 216 p. Academic, New York.

Wicker, E. F. and C. G. Shaw.
1967. Target area as a klendusic factor in dwarf mistletoe infections. Phytopathology 57: 1161-1163.

DWARF MISTLETOE MANAGEMENT IN THE PACIFIC NORTHWEST[1]

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Abstract: Most Pacific Northwest foresters know how to control dwarf mistletoes. High levels of control are being obtained because foresters are assigned control responsibility, training is continuously provided, and money is available. Dwarf mistletoes are managed by treatment unit layout, overstory removal, residual removal, sanitation thinning, stand replacement, species manipulation, pruning, and combination treatments. Dwarf mistletoe control techniques are an integral part of forest management.

INTRODUCTION

Dwarf mistletoes are estimated to reduce Oregon and Washington forest productivity by 148 million cubic feet annually. There are eight dwarf mistletoe species and 19 tree species affected. The most serious damage occurs in Douglas-fir, western hemlock, ponderosa pine, lodgepole pine, and western larch. Dwarf mistletoes are thought to occur on about one-half of the forest land in these two States. True mistletoes occur on Oregon oak, incense cedar, and juniper.

Projects with the sole objective of controlling dwarf mistletoes were not initiated in the Pacific Northwest until 1959. This seems somewhat surprising because as early as 1916 James Weir, one of the first forest pathologists to visit the Pacific Northwest, had clearly documented the seriousness of dwarf mistletoe damage. He suggested control procedures which are still appropriate today.

Dwarf mistletoes were certainly not ignored by Pacific Northwest foresters prior to 1959. They were considered in most forest operations; their presence influenced selection of sites to be cut, methods of harvesting, size of cutting units, and reforestation practices. Mistletoes were being controlled by routine forest operations.

When dwarf mistletoe control programs first began in the early 1960's, the idea was to eliminate all or nearly all mistletoe from treatment areas. Eradication is possible in clearcutting operations but in thinnings and uneven-aged management, primarily east of the Cascades, total mistletoe removal can seldom be. Now foresters ask "How much dwarf mistletoe can I tolerate and still grow a productive forest?" This makes mistletoe management more compatible with other forest management practices and it calls for much more professional judgment.

The goal of Pacific Northwest dwarf mistletoe management is to reduce the parasites to levels that allow trees and stands to grow at acceptable rates without incurring undue costs in control efforts.

Most Pacific Northwest foresters understand how to control dwarf mistletoes and are applying mistletoe management practices. Dwarf mistletoe management is more than ever before an integral part of management activities on most forest lands in Oregon and Washington. Mistletoe control is viewed along with precommercial thinning, selection of genetically superior trees, and fertilization as an intensive management tool to increase forest productivity. Many thousand acres receive dwarf mistletoe treatments each year. Part of this high level of control can be attributed to the good growing conditions in the Region and the favorable economic position of forestry, but mostly it is due to the average forester's good understanding of dwarf mistletoes. Mistletoes are managed more intensely on Federal and State forests than on most private holdings, but many of the industrial forestry companies are aggressively controlling the disease.

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GAINING COMMITMENT

It may seem to some that a discussion on gaining commitment is out of place at this symposium. However, based upon our combined 19 years of experience with dwarf mistletoe control in the Pacific Northwest, we feel strongly that without foresters' commitment, control programs will not work. Most western foresters know the damaging effects of mistletoes. Forest pathologists incessantly speak of the evils of dwarf mistletoes and exhort foresters to control them. However, in many cases these actions are not enough. Control opportunities are missed because there is lack of commitment at one or more organizational levels.

The importance of gaining foresters' commitment to dwarf mistletoe control has been recognized by most people responsible for developing the programs in Oregon and Washington. Three actions have been taken--public agencies and some companies have officially declared it their policy to control mistletoes, training is being provided continuously, and funds are made available for dwarf mistletoe management.

The Forest Service Pacific Northwest Region and Washington State Department of Natural Resources (WDNR) have declared it their policy to reduce losses caused by dwarf mistletoes on lands they administer. These declarations assign responsibilities for mistletoe management. Guidelines are provided for managing mistletoes in numerous Pacific Northwest forest conditions. Other public forest land managing agencies have policies calling for reduction of disease losses but dwarf mistletoes are not specifically identified in the statements.

Dwarf mistletoe control guidelines and policy statements have to be clearly understandable, present attainable goals, and be based on facts. If they are too general, difficult to understand, or present unattainable goals, they will be ignored. People charged with carrying out these instructions have more commitment if they are involved in their formulation.

The issuance of directives is not, of course, totally responsible for commitment to control mistletoes. They are a contributing factor because they can be used to hold people accountable for their actions or lack of them. Without written policies and guidelines dwarf mistletoe management is left to the discretion of individuals. This has usually resulted in only interested people performing control and widely varying standards of work quality. This problem can be seen on some private lands.

Training has probably been among the most effective means of attaining high levels of commitment to dwarf mistletoe control in Oregon and Washington. The Forest Service conducts forest insect and disease management workshops on at least six National Forests per year. Dwarf mistletoes are a major topic, with emphasis being placed on practical management approaches. State forestry organizations provide the same type of training. In addition, the Forest Service has developed a 2-day dwarf mistletoe workshop which is presented upon request. Training pays big dividends because it keeps dwarf mistletoe on foresters' minds, provides an outlet for research findings, exposes the subject to those unfamiliar with mistletoes, and provides exposure of pathologists to people who need their services. Plans are well underway to provide dwarf mistletoe training to privately employed foresters in the two States under the auspices of the Northwest Forest Pest Action Council.

Oregon and Washington State forestry agencies and the Forest Service have all prepared easy to read how-to-do-it dwarf mistletoe publications. The latest is "Dwarf Mistletoes of Oregon" by the Oregon State Department of Forestry. One of the first management publications was "A Training Aid on Dwarfmistletoe and Its Control" by Donald Graham, issued in 1967. Several thousand copies were distributed and requests are still being received. This one publication probably contributed more to Pacific Northwest foresters' knowledge of mistletoes than anything else.

The WDNR and Forest Service have demonstration areas for training foresters how to recognize and manage dwarf mistletoes. Both good and bad techniques are shown. The purpose of the areas is to demonstrate how prescriptions offered in guidelines, publications, and training sessions are actually applied and look. In most cases demonstration areas are also study plots. Plans call for establishment of many more demonstration sites.

Directives and training are important to gaining commitment, but it is money that accomplishes dwarf mistletoe control in the Pacific Northwest. Allocation of funds for dwarf mistletoe control emphatically states management commitment.

Appropriation of funds by the Forest Service specifically for dwarf mistletoe control started in 1959 and reached a peak early in the 1970's with close to $400,000 being spent in one year. The WDNR has made about $190,000 available to its districts for control. Crown Zellerbach Corporation has recently budgeted money for hemlock dwarf mistletoe control in Washington. Since 1959, close to 2 million dollars have been obligated specifically for control in the Pacific Northwest.

A highly important benefit achieved by allocating these funds is stimulation of foresters' awareness of the need for and value of dwarf mistletoe control. Dwarf mistletoe control funds have served as seeds to spark interest. Once foresters become aware of the desirability and feasibility of controlling dwarf mistletoes, they rely less on funds specifically earmarked for control and more on regular timber stand improvement and sale preparation funds. Today at least five times as much acreage is treated with these funds than with dwarf mistletoe control funds.

We believe that these actions, specific policy direction, training, and funding form the basis for the high level of commitment Pacific Northwest foresters have to dwarf mistletoe control.

DWARF MISTLETOE MANAGEMENT TECHNIQUES

Treatment Unit Layout

Layout of dwarf mistletoe treatment units is important both in keeping costs down and preventing spread into new regeneration or sanitized stands. Borders of treatment units should incorporate natural and manmade barriers to prevent or slow reinvasion. Barriers which have been used include: Small natural openings in stands, larger meadow edges, timber type species changes, uninfected edges of the same timber type, rock outcrops, streams, lakes, roads, power lines, adjacent clearcuts, and others. Ridge tops do not make good boundaries because upwelling winds can carry dwarf mistletoe seed over the top. Valley bottoms are better. Barriers should be about 1 chain wide, but we have recommended narrower strips; particularly if the dwarf mistletoe species present does not discharge its seeds long distances.

Dwarf mistletoe infestations do not normally occur continuously over large areas. Instead, the pattern consists of infected, then noninfected zones scattered throughout stands. Foresters are encouraged to include entire stands in control units rather than treat infected portions so drastically different that new smaller stands are created where only one previously existed. For example, we would recommend that foresters not patch cut 1- to 2-acre mistletoe-infected spots in a 50-acre pole-size stand but consider sanitizing the entire stand. Generally, the smallest unit of commerical forest land managed separately is 5 acres. Smaller units are considered too costly to manage.

Clearcut corridors along edges of treatment units are discouraged primarily because of cost. It is better to readjust boundaries if possible. Cleared strips are sometimes used where treated acres adjoin old-growth infected trees of different ownership. Since dwarf mistletoes are quite host specific, infested or susceptible species are kept out of a 1 chain wide strip separating treated and untreated stands. Resistant species are either retained, planted, or allowed to regenerate naturally in the strip.

Treated units are often left with infected perimeters when adjacent stands will be harvested within 5 to 10 years. Only a small amount of dwarf mistletoe infection would occur in this short time. This requires careful long-term planning and follow-up.

Foresters are encouraged to design treatment units, especially clearcuts, with as large an area-to-perimeter ratio as compatible with other management considerations to prevent rapid reinvasion. In infected stands, where there is little opportunity to create uninfected edges, large, circular shaped clearcuts are favored over smaller long, narrow, clearcuts. To illustrate the potential importance of this point, consider the following example. There are two 30-acre clearcuts. One is circular, the other rectangular with dimensions of 10 by 30 chains. If the entire perimeters of both are infected and they are regenerated with susceptible tree species, the rectangular unit will be reinvaded fastest. After 15 years, 23 acres of the circular unit will be uninfected; but in the rectangular unit slightly less than 21 acres will be uninfected. Recommendations on size and shape of treatment units should be developed in consultation with landscape architects and wildlife biologists to avoid potential conflicts.

Overstory Removal

Dwarf mistletoes spread most rapidly in multi-story stands. Control activity is usually directed at creating single story stands. For example, an infected stand of old-growth ponderosa pine with a well-stocked but infected understory would first have the overstory removed, then the infected understory would receive a sanitation-precommerical thinning. Overstory removal is practically always accomplished by timber sales. Occasionally, scattered infected overstory will be either dropped or left standing and girdled.

A simple technique we have found useful in overstory removal is to paint the stumps of overstory trees which are infected. This alerts crews who will be thinning at a later date to examine trees surrounding painted stumps closely for infections.

The shelterwood system is a proven method for successfully regenerating Douglas-fir and other species on certain sites. Occasionally it is necessary to leave infected trees to provide shelter. When susceptible regeneration develops under infected shelterwood, the infected overstory should be removed as soon as the regeneration is established. The Forest Service uses a rule that infected overstory should be removed before regeneration reaches 3 feet tall or 10 years old, whichever occurs first. WDNR recommends for western hemlock management that infected overstory be removed within 5 years.

Most commerical forest land in the Pacific Northwest is, or will be, under even-age management, so removal of infected overstory trees is considered standard operating procedure.

Residual Removal

Infected trees often remain after stands are clearcut or burned. Pacific Northwest loggers, a proud group of rugged individualists, often consider it beneath them to cut unmerchantable size trees when clearcutting. Standard clauses in Forest Service and WDNR clearcut timber sale contracts require all trees above 4 inches dbh be cut. Smaller trees which may be infected can be left. The WDNR has clauses which may be inserted in timber sale contracts requiring a cleancut where all stems are to be severed when dwarf mistletoe is present. Many agencies, companies, and small landowners have no requirements concerning removal of trees in clearcuts. Many clearcuts are not broadcast burned, allowing infected residuals to survive. Wildfires usually do not kill all trees within burns.

These residuals constitute an infection threat to susceptible regeneration. For example, it was shown that dwarf mistletoe plants in one western hemlock on Vancouver Island, British Columbia, cast seeds over an area encompassing 5,800 square feet (0.13 acre). Less than eight of these trees, evenly spaced, could serve to spread mistletoe seeds over an entire acre. It is not at all uncommon to have more than eight infected residuals left per acre after clearcutting. We estimate that untreated residuals will cause at least 8,000 square feet around them to be unproductive in a normal rotation.

In many cases, infected residuals left after clearcutting will be killed by slash burning. Residuals are also removed for other reasons, such as firewood cutting or to reduce hazards to brush spraying helicopters.

Residual removal is one of the most effective and least costly dwarf mistletoe control techniques used in the Pacific Northwest. Considering that more than 360,000 acres are clearcut each year and that about 30 percent of this area may be infected, residual removal provides excellent opportunity for greatly reducing losses, particularly when it can be accomplished during logging.

Mistletoe control is frequently the only reason residuals are destroyed. Forest Service policy is to use money (K-V) from timber sales for this. When these funds are not available, other funds (P&M or FIDM) will be allocated. Top priority for Forest Service dwarf mistletoe control funds in the Pacific Northwest is residual removal.

Existing management guidelines do not specify how many infected residuals per unit area are required for control to be initiated. However, we would certainly recommend treatment even if there were as few as one tree per acre. If clearcuts are less than 5 years old, all living residuals of the infected tree species are killed. When there are numerous residuals and the stands will not be broadcast burned, we recommend treatment efforts be concentrated on those 3 or more feet tall; but we would prefer to see all destroyed. Foresters are encouraged not to attempt to save apparently uninfected trees because they may have latent infections. If clearcuts are 5 or more years old, only visibly infected trees have to be killed although we encourage all trees be treated.

Cutting residuals is preferred to girdling or poisoning because it guarantees trees will be killed and it is easier to check work thoroughness. In some instances, trees are girdled or poisoned, particularly if needed for wildlife.

There have been several occasions when an agency or company with several thousand acres of clearcuts, ranging from less than a month to more than 20 years old, has decided to initiate residual removal for dwarf mistletoe control. Usually we advise them not to do residual removal as a separate operation on units more than 15 years old. It should be combined with sanitation precommercial thinning. The 10- to 15-year-old units are treated first because studies have shown the rate of stand infection increases rapidly once trees reach this age. The 5- to 10-year-old units are treated next and finally the 0 to 5 units until the backlog is eliminated.

Experienced crews can treat residuals during slow seasons, instead of being terminated. Unemployed people or youth crews can do this work with a small amount of training.

Residual removal costs vary tremendously depending upon number and size of trees, topography, and availability of labor. We have seen costs from $5 to over $200 per acre. Costs seem to average less than $40 per acre.

Foresters are urged to eliminate residuals during logging or reforestation. We have had success in getting loggers to knock over residuals as they are yarding logs to landings. High lead logging destroys more residuals than tractor, skyline, helicopter, or balloon logging. Broadcast burns are advocated, if ecologically sound for the sites. Pathologists advocate cleancuts instead of clearcuts.

Sanitation Thinning

In the late 1960's when dwarf mistletoe control was first begun on WDNR lands east of the Cascades, a few problems were encountered. Logical steps to control are to: (1) remove infected overstory, (2) sanitize infected understory by specialized precommercial thinning, and (3) follow-up 5 to 7 years later if necessary. Managers had difficulty finding acres eligible for precommercial thinning-sanitation because infected overstory was almost always present. Years of selective logging with occasional regard for dwarf mistletoe control had produced these stands.

It often became necessary to set up special timber sales just to provide acres for the precommercial thinning-dwarf mistletoe control. The cart was before the horse! Now, a better approach is being used: (1) dwarf mistletoe problem areas are identified, (2) the infected area is gradually converted to single story management through carefully planned overstory removal timber sales, and (3) the more or less even-aged shorter stand is sanitized while being precommercially thinned.

Note that the order of doing things is about the same as described above but the priorities are different! Instead of trying to find suitable stands for precommercial thinning first, the manager begins with the timber sale recognizing that if dwarf mistletoe is to be reduced only one level of canopy can exist. The disease control operation is now integrated with normal management.

Dwarf mistletoe sanitation on WDNR lands has been concentrated in ponderosa pine stands. The Hawksworth mistletoe rating system is used to select trees for removal. The amount of infection a tree can have and still be kept in a stand depends upon its size. The following table lists allowable ratings.

dbh Class	Maximum Allowable Rating
1-2	0
3-4	1
5-6	2
7+	3

Cutters are required to cut or kill all trees exceeding these ratings. Oregon State Department of Forestry advocates the same system.

Sanitized areas are examined 5 to 7 years after treatment to determine success and decide if additional treatment is necessary.

Forest Service dwarf mistletoe sanitation thinning guidelines differ somewhat from those of the WDNR. The guidelines apply to all tree species and a different infection severity rating system is used.

Sanitation is an integral part of all thinnings in infected stands. Expenditure of funds for sanitation is limited to lightly infected precommercial size stands from which all overstory has been removed. Severely infected stands are replaced rather than thinned.

Stand infection severity is not based directly upon the standard 0 to 6 rating system even though it is used in routine stand examination surveys. Stand infection intensity is rated none, light, or severe. It is based upon the number of potential crop trees for the site. Silviculturists have determined acceptable stocking levels for many tree species by site index. Presence of mistletoe affects crop tree potential. In stands where the average potential crop tree dbh is less than 2 inches, crop trees should have no visible infections. They should meet all other crop tree criteria. In stands with potential crop tree dbh averaging 2 inches or larger, priorities for crop tree selection are as follows.

1. Uninfected dominants and codominants.

2. Dominants and codominants with dwarf mistletoe confined to branches in the lower one-third of live crown.

3. Dominant and codominants with dwarf mistletoe confined to less than 50 percent of the branches in the lower one-half of live crown.

4. Intermediates with no visible infections.

These priorities correspond roughly to ratings of 0, 1, and 2, 3, and 0 using the standard mistletoe rating system.

If enough trees meeting these criteria exist to achieve acceptable stocking, the stand would be rated lightly infected. Stands are considered severely infected if there are not enough trees with the above characteristics to meet minimum stocking guidelines for the particular site.

This approach allows selection of trees based upon severity and location of infections. Trees with upper crown infections are not potential crop trees. Research has shown high crown infections cause more growth impact and contribute more tree-to-tree spread than lower crown infections. We feel one of the strong points of this crop tree selection method is that foresters must consider other tree and site characteristics in addition to mistletoe.

In the first several years of the Forest Service mistletoe control program, emphasis seemed to be placed upon eliminating infected trees during thinning. Little regard was paid to superior tree characteristics, resulting in many stands that look like silvicultural abominations. Dominant and codominant trees were felled, even if they were only lightly infected, and suppressed trees were chosen for crop trees because they were seemingly uninfected. Large openings were created where all infected trees were cut, regardless of infection intensity. Spacing and stocking was erratic. Good silvicultural practices were abandoned in the zeal to eliminate mistletoe. Fortunately, this problem has been corrected. Stands sanitized under present standards often contain infected trees to provide adequate stocking but they will grow at acceptable rates. Tree killing by dwarf mistletoe is uncommon in thinned stands.

Forest Service sanitation thinning guidelines recommend against spending funds for resanitizing stands. We feel foresters will remove the most severely infected trees in the first entry. Infected trees which may be left are capable of reaching merchantable size by the time of normally scheduled commercial thinnings or regeneration cuts. Infected trees may cause some infection in adjacent trees, but usually these new infections will be low in the crown and have little effect on growth.

The importance of spacing is stressed in stands with infected crop trees. A minimum spacing distance of 12 feet is recommended in precommercial size stands if infected trees are to be left. Infection by contagion declines when spacing between trees increases. Theoretical calculations for ponderosa pine have indicated that infection by contagion is greater at spacings of 9 feet and lower at 18 feet. Infected crop trees must have sufficient space for good growth response so annual height increment will exceed upward spread of dwarf mistletoe. Spacings suggested for mistletoe-infected stands are essentially the same used in healthy stands.

Existing sanitation guidelines apply uniformly to all species. However, we advise foresters to discriminate more severely against infected Douglas-fir and hemlocks than true firs, pines, or larch, because they suffer more damage.

Forest Service and Oregon State Department of Forestry sanitation guidelines suggest use of a Canadian developed formula to assist thinners in locating infected trees. It assumes spread from a single source, such as a residual to surrounding regeneration. The formula is distance (ft.) = initial spread + ([years since logging - 5] x 2). Trees within this distance of an infected residual should be examined carefully for infections. For example, in a hemlock stand logged 15 years ago the following calculations would apply.

Distance = 40 + ([15 - 5] x 2) = 60 ft.

Forest Service pathologists are frequently asked for advice on thinning stands which appear to be severely infected. Usually the best trees average at least 4 inches dbh. They are too small for commercial thinning and too large for precommercial thinning. Left untreated, such stands tend to disintegrate. Frequently we recommend they be thinned even though leave trees may have numerous infections. We suggest these thinned stands be grown to minimum merchantable product size and then replaced early rather than carrying them the normal rotation period. Infected trees which are 4 inches dbh can usually be grown at least 8 or 9 inches in 20 years, even on poor sites.

Sometimes it is desirable to delay sanitation thinning infected western hemlock stands of precommercial size until the average potential crop tree is 4 to 5 inches dbh. If infected trees are released when they are only 1 to 3 inches dbh, hemlock mistletoe intensifies rapidly and causes severe reductions in growth. When these stands are allowed to grow in their normal dense condition, many infections which are located low in the crowns become shaded and die. When these trees reach 4 to 5 inches dbh the top halves of crowns are often mistletoe free. After the stands are thinned, canopies usually close in 5 years and trees often grow to merchantable size in 10 or less years on the best sites.

Occasionally, two-storied stands are found which have a moderately dense infected overstory and fully stocked understory. It may be difficult to tell if the understory is severely infected because shading has not allowed vigorous development of aerial plants and witches' brooms. If such sites are not difficult to regenerate, the recommendation often given is to remove all overstory then wait 3 years before thinning the understory. The 3-year period will allow most mistletoe present at the time of overstory removal to become readily detectable. If the stand appears to be severely infected at this time, it would be destroyed and the site regenerated.

The importance of having thinners trained to recognize dwarf mistletoe infections is stressed. Most sanitation thinning is accomplished by contractors and many, when first starting, do not recognize dwarf mistletoes. Aids are provided to help them select proper crop trees. Contracts describe desirable crop trees; some require thinners to use the 0-6 rating system for crop tree selection. Others use the previously described crop tree criteria. Contract descriptions have to be simple to be understood and applied.

Stand Replacement

The only practical alternative for severely infected stands is to regenerate them so site potential can be realized. Under Forest Service guidelines a stand is considered severely infected if removal of undesirable trees would leave it understocked.

Clearcutting is the most common method of regeneration cutting. It is most frequently employed west of the Cascade Crest but has been used many times to remove mistletoe-infected stands on the east side. Shelterwood cutting is increasingly used. Both systems have already been discussed.

Some interesting methods have been used to replace severely infected stands on sites considered difficult to regenerate. On at least two severely infected sites all merchantable volume was removed. The stands were then burned, and seedlings were planted in the shade of dead trees. Consideration has been given to spraying severely infected stands with herbicides then planting in the shade. Another approach used in ponderosa pine stands was to remove merchantable volume, followed by a mechanical brush cutter to create cleared swaths approximately 20 feet wide through the very dense, severely infected understory. Leave strips were 4 to 6 feet wide. Seedlings were planted in the cleared swaths and as soon as they become established the remaining infected trees will be destroyed.

Forest Service guidelines recommend that infected stands of small diameter true firs not be destroyed for the sole purpose of dwarf mistletoe suppression. Research conducted by the PSW Station indicates true firs with good crowns will usually grow well in spite of infections if they are released.

Species Manipulation

Most dwarf mistletoe species found in the Pacific Northwest have limited host ranges. One major exception is hemlock dwarf mistletoe, which in addition to infecting western and mountain hemlocks, commonly infects all true firs (Abies) and occasionally western white pine.

Species manipulation is used as a dwarf mistletoe management technique in several ways in the Pacific Northwest. Where perimeters of stands adjoining plantations contain infected trees that can cast mistletoe seeds onto regeneration in the cut areas, 50- to 100-foot wide strips along the edges are sometimes planted with nonsusceptible trees. Occasionally it might be necessary to remove susceptible seedlings which regenerate naturally in the strips. A variation of this approach that has been used only occasionally is to harvest infected species for a distance of 50 to 100 feet into stands surrounding plantations.

Shelterwood cuts are becoming increasingly common in the Pacific Northwest. Nonsusceptible species of seedlings are often planted under infected shelter trees. Ponderosa pine is frequently planted under infected lodgepole pine. Douglas-fir is often planted under or close to infected hemlock and true firs.

Species manipulation is advantageous during thinnings. Uninfected species are favored as crop trees. Common examples include favoring Douglas-fir instead of hemlock in infected stands in western Oregon and Washington, and white fir instead of infected Douglas-fir in eastern Oregon and Washington. In some areas, particularly southern Oregon, there may be three different species of dwarf mistletoe on a single acre--Douglas-fir, hemlock, and white fir--and all tree species may be infected. Foresters will favor trees least damaged by mistletoe, usually white or red fir. Another example occurs in higher elevations in the Cascades where hemlock mistletoe often infects true firs and hemlocks in the same stands. True firs are favored because mistletoe damages them less than hemlock. This situation often becomes complicated because some true firs are severely damaged on these sites by balsam woolly aphid. Fortunately, true fir susceptibility to the aphids varies with elevation.

Species manipulation provides about the only hope for uneven-age management of dwarf mistletoe-infected stands. It also is one of the very few ways to manage infected stands that have been designated for rotations as long as 200 years because of visual or wildlife management considerations. Numerous examples of species manipulation have been applied in stands visible from heavily travelled highways in eastern Washington and Oregon. West of Wenatchee, Washington, foresters have removed mistletoe-infected Douglas-fir and larch from stands which also contain white fir, Engelmann spruce, ponderosa pine, and lodgepole pine. The area was referred to as a silvicultural slum because of the large number of dead trees. It is now much more scenic because of the species manipulation.

Pruning

Pruning is not recommended in forestry operations, except in incidental cases where infections can be removed at no additional cost while precommercial thinning. It is recommended only in campgrounds or recreational sites where trees are a premium.

Coastal recreation sites are frequently located in western hemlock stands. Heavily infected crowns produce dwarf mistletoe brooms that may weigh up to 200 pounds or more. Falling broomed branches could severely damage property or injure recreationists. Pruning heavy brooms in these stands is a good practice.

East of the Cascades, pruning of dwarf mistletoe brooms is occasionally done to enhance tree vigor in recreation sites. Ponderosa pine responds most favorably to pruning when at least half of the upper crown is either uninfected or only lightly infected. The lower infected crown is pruned away. Douglas-fir benefits even more from pruning of brooms.

Combination Treatments

In many dwarf mistletoe-infected stands, a combination of control treatments is used. For example, in two-storied ponderosa pine stands overstory is removed, then infected understory receives a sanitation thinning. If the understory is severely infected, it might be destroyed and the overstory partially removed. The site is then planted and as soon as the seedlings become established, the remaining overstory is removed. In some stands, severely infected spots may be destroyed, while adjacent lightly infected areas are thinned, favoring uninfected species.

In older clearcuts residual removal is combined with sanitation thinning, species manipulaton, and sometimes removal of infected edge trees.

Dwarf mistletoe control treatments frequently reduce other pest damage. For example, sanitation thinning infected ponderosa pine stands makes them less susceptible to mountain pine beetle attacks and possibly Elytroderma needle blight.

Contracts

Practically all dwarf mistletoe control on WDNR and Forest Service lands is done by contractors.

Mistletoe contract clauses must be uncomplicated. Long, detailed descriptions of dwarf mistletoe conditions on trees were found undesirable and unreal in early control contracts. The WDNR incorporates the 0-6 Hawksworth rating system into their precommercial thinning contracts and issues walletsize cards with rules on them to aid thinners. They have found this system highly reliable. Timber sale contracts have a standard list of clauses managers can choose that will help reduce the parasites.

The Forest Service has contracted several dwarf mistletoe surveys. In all cases other stand information has been collected during the same surveys.

Post Suppression Evaluation

Quality of dwarf mistletoe suppression must be monitored. Forest pathologists continuously monitor control programs, even those which are not accomplished with dwarf mistletoe control funds. All work done under contract is examined for compliance. WDNR uses a plot system to evaluate long-term control effectiveness.

NEEDED IMPROVEMENTS

Although we feel the mistletoe control programs in Oregon and Washington are successful, they can be considerably improved.

Training.--Privately employed foresters and small landowners presently are not receiving training on dwarf mistletoes. Fortunately, it looks like this is soon to change because the Northwest Forest Pest Action Council is going to conduct insect and disease workshops. How-to-do-it publications and slide-tape programs are needed because many foresters are unable to attend training sessions. More demonstration plots should be established. Mistletoe needs to stay in the news.

Impact.--Research is needed on the ability of infected trees of all species to respond to release. This information is practically nonexistent for western hemlock and scanty for Douglas-fir. Much of the past mistletoe research was conducted in unmanaged stands--we are interested in managed stands.

Yield Programs.--Simulated yield programs such as RMYLD are not available for the Pacific Northwest. They would be helpful management tools.

Economics.--The economic benefits of dwarf mistletoe control have not been adequately investigated. We strongly suspect control has a favorable benefit/cost ratio, but with some exceptions this has not been confirmed. More economics research is needed.

Coordination.--There is a need for better coordination between forest pathologists, landscape architects, wildlife biologists, ecologists, and silviculturists. In numerous occasions these disciplines have offered conflicting advice to foresters. Landscape architects and wildlife biologists need a better understanding of mistletoe epidemiology and damage. Pathologists need to understand the other disciplines' objectives and techniques.

DWARF MISTLETOE CONTROL ON THE ROGUE RIVER NATIONAL FOREST IN OREGON[1]

R. Duane Kingsley[2]

Abstract: Dwarf mistletoe treatment strategy is reviewed for clearcuts, shelterwoods, and uneven-aged management areas on the Rogue River National Forest in southwest Oregon. Stand cleaning is not attempted in old-growth stands, but is instead concentrated at the time of regeneration cutting, with some follow-up stand cleaning in young stands. Administration requires data gathering that is location oriented and job specific, with a good record keeping system. Each unit manager should be held responsible for the effectiveness of the dwarf mistletoe control program on his unit.

Key words: Dwarf mistletoe, stand cleaning, regeneration cutting, clearcuts, shelterwood, uneven-aged management.

INTRODUCTION

The Rogue River National Forest is one example of a Pacific Northwest dwarf mistletoe situation. A considerable amount of control work has been done, and the results look promising.

The Rogue River National Forest contains about 621,000 acres of land in extreme southern Oregon and northern California on the west slope of the Cascades and the northern part of the Siskiyou Mountains. The center of the Forest is about 100 miles inland from the Pacific Ocean, so the climate is essentially warm and moist in the winter, but hot and dry in the summer.

About 80 percent of the Forest is managed for some type of commercial wood production. The average elevation of these lands is 4,300 feet, with extremes as low as 1,800 feet and as high as 7,000 feet elevation.

We are blessed by 10 major timber species of conifers, principally Douglas-fir (Pseudotsuga menziesii), white fir (Abies concolor), Shasta red fir (Abies magnificia var. shastensis), ponderosa pine (Pinus ponderosa), sugar pine (Pinus lambertiana), western white pine (Pinus monticola), and some western hemlock (Tsuga heterophylla). But at the same time, we are cursed by 5 species of dwarf mistletoe, sometimes up to 3 species on the same acre. By far the worst in terms of virulence and damage on this Forest are Douglas-fir (Arceuthobium douglasii) and hemlock dwarf mistletoe (A. tsugense).

We have some kind of dwarf mistletoe problem on approximately 75 percent of the Forest, but using the guidelines I will describe, we have cleaned about 100,000 acres from dwarf mistletoe.

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[1] Presented at the Symposium on Dwarf Mistletoe Control Through Forest Management, Berkeley, Calif. April 11-13, 1978.

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To understand what we have done, and what is still unfinished, one must first know something about the overall timber management cycle from old-growth, to plantation, to pole stand, to mature timber.

No stand cleaning is attempted in old-growth stands. The first dwarf mistletoe treatment in mature stands is a regeneration cut to remove all the excess trees, prepare the site, and start a new plantation.

As the plantation grows, it is precommercially thinned at about age 15 to leave the best 320 trees per acre. At about age 40, the average stand will receive a commercial thinning to remove the excess trees and leave the best. Thereafter, a light thinning will be done every 15 years until the stand is mature at about age 85. At that time the stand will be regenerated again with a new plantation.

In review, many old-growth stands are heavily infected with dwarf mistletoe. We make no attempt to clean these stands by partial cutting. The best chance to rid an area of dwarf mistletoe happens only once every 90 years, during the regeneration cut. We feel that if we bungle this opportunity, chances are we will have condemned the land to another 85 years of infection with all the associated growth losses, mortality, etc.

Therefore, the regeneration cut is where our major effort is placed. With some subsequent stand cleaning during future entries, we feel the program will be successful.

OPPORTUNITIES FOR DWARF MISTLETOE CONTROL DURING REGENERATION CUTTING

Each type of regeneration cutting requires a somewhat different treatment approach.

Dwarf Mistletoe Control in Clearcuts

In clearcutting, all the trees on a block of land are cut at once. After disposal of the slash, usually by burning, the area is reforested clean of dwarf mistletoe. Our job is to keep it clean by removing sources of reinfection.

Using Douglas-fir as an example, reinfection can occur if any infected Douglas-fir residual whips or seedlings are left in the area after cutting and burning. These must all be cut, injected, or otherwise killed. When the tree dies, so does the mistletoe. Even though these trees often contain some usable wood, they must be killed. If they can be utilized in some way, such as for fuelwood, fine. But any wood lost is likely to be insignificant in comparision with the damage reinfection could cause.

A second source of infection in clearcuts is from the surrounding uncut timber. There are several treatement options.

1. In mixed species stands, log out the infected species at least a chain or more back into the timber, so dwarf mistletoe seeds cannot pop out into the new plantation. With good planning this chain wide strip can often be included in the sale and logged at the same time as the clearcut, or

2. If it is not possible to remove infected edge trees before planting, they should be removed before the susceptible seedlings reach 3 feet in height or 10 years of age, whichever occurs first, or

3. Where it is not possible to move the infection edge away from the susceptible seedlings, then the susceptible seedlings must be moved away from the timber. A strip extending about 100 feet into the plantation should be reforested with a tree species not susceptible to that species of dwarf mistletoe. In some cases it may be necessary to remove susceptible natural seedlings which become established in the strip.

Dwarf Mistletoe in Shelterwoods

Shelterwood is another system used to regenerate a timber stand. Shelterwood cutting on the Rogue River National Forest is usually done in blocks, some as small as 10 acres, and some as large as 700 acres. In this type of cut the canopy is rather uniformly opened by logging, while leaving sufficient trees to provide seed and shelter for a new crop of seedlings.

When the plantation is well established, the remaining overstory trees are removed, either in a series of cuts or all at once, depending on the physical situation at each site. Where frost protection is a major consideration, the overstory may have to be left for long periods of time, even up to 40 years.

In block shelterwoods, reinfection of the plantation can be prevented in several ways:

1. Remove all the trees of the infected species the first cut. For instance, if Douglas-fir is infected, and Douglas-fir is to be used for reforestation, leave no Douglas-fir overstory trees in the overstory. Select leave-trees only from species other than Douglas-fir, or

2. Remove the infected overstory species shortly after the susceptible species in the plantation are established, before the seedlings reach 3 feet in height or before they reach 10 years of age, whichever occurs first.

Recognize that some infection will probably occur, and that all subsequent thinnings will require careful stand cleaning wherever infection centers are found. In this case, it is helpful to mark the stumps of the infected overstory trees so the potential infection centers can be identified later.

It is also helpful to use a broad mix of native tree species in the plantation. This helps to prevent the rapid spread of dwarf mistletoe seeds from tree to tree. It also makes it possible to clean out an entire group of trees of the infected species, and still have sufficient trees of other species to stock the spot, or

3. Shift the species composition of the plantation to some less susceptible species. For instance, if Douglas-fir is infected in the overstory, plant pine underneath, or white fir, or whatever species fits the site.

The problem is that Douglas-fir will surely seed in, and those seedlings might become infected. However, Douglas-fir can be discriminated against during precommercial thinning and commercial thinning so as to keep it a minor component of the stand. And assuming that a good job was done in establishing the other species in the plantation, the losses in the Douglas-fir will be a minor part of total stand production.

4. In all cases, protect the perimeters of shelterwood plantations from infections in the surrounding timber, as discussed in the section on clearcuts. After overstory removal, shelterwoods look like clearcuts anyhow, so the same guidelines apply.

Dwarf Mistletoe Control in Uneven-aged Management Areas

Uneven-aged management is a silvicultural system that carries trees of all sizes on the same acreage, without any massive regeneration cut at any one time. Instead, a few trees of each size class or a small group of trees are cut on some periodic re-entry cycle, such as every 15 years. The holes created are reforested, and the stand tends to remain about the same through time.

Uneven-aged management is suited to certain special situations such as campgrounds, scenic highway strips, important streamsides, sensitive trails, unstable landslide areas, and areas of poor site or extreme reforestation difficulty.

Dwarf mistletoe control in uneven-aged situations is very difficult, though not entirely hopeless. The stand situations favorable to dwarf mistletoe propagation are all present. A source of infection is always available in the older trees. There is plenty of sunlight. And there are always younger trees to become infected and carry on the disease.

It might sometimes be possible to remove all the trees of the infected species, and install a clean plantation of the susceptible species. But this alternative will seldom be possible because of the light cuts inherent to uneven-aged management and because so many of the infected trees are smaller than merchantable size.

Generally, the only strategy we have available for uneven-aged stands is some type of species manipulation within the timber stand.

This could be done by planting immune species underneath the infected stand, and discriminating against the susceptible species until all the susceptible trees are gone in that portion of the stand. When there is no remaining source of infection, the susceptible species can be reintroduced into the cleaned area by planting.

If dwarf mistletoe is spotty, then only the infection centers need such treatments. But if the infection is widespread, then a species shift would be necessary in the whole block.

If several species of dwarf mistletoe exist on the same acre, it may be impossible to clean all the species at once. Instead, the manager may have to decide which dwarf mistletoe species he is going to eradicate and which he is going to ignore for the present.

ADMINISTRATION

In closing, let me describe some problems we are having in hope that others might be able to avoid them or solve them.

1. Dwarf mistletoe surveys, or careful walk-throughs, or whatever is used to identify dwarf mistletoe problems, should be location oriented. Building a large volume of coded plot cards will expend the funds, but may not accomplish anything if they are lost in the storeroom or in a computer bank someplace. We want maps with specific locations and work orders so we can go out and get the needed work done.

2. A good record keeping system is needed showing what has been done and what needs to be done in the future. Do your records show what is to be done, where, when and why? Could a stranger figure it out, or do you have to be there to explain it?

3. Record keeping systems must be capable of prompting future actions. As an example, how will the land manager 20 years from now be prompted to make a careful inspection and sanitize the dwarf mistletoe infected Douglas-fir trees in the south 1/2 of unit 217? If your system does not provide for this type of prompting for future actions, the benefits of any dwarf mistletoe actions taken now will probably dribble away in time.

4. The effectiveness of a unit's dwarf mistletoe control program should be made a part of every manager's performance rating.

Someone must be charged with the responsibility for getting the job done. To date, in most organizations, the managers have been made aware of what needs to be done, and they are encouraged to proceed. But if they don't happen to take an interest, or they decide it's not important, nothing happens. They can still get high ratings for civil rights, and getting out the cut, etc., and move on up the promotion ladder, but leave a dwarf mistletoe mess behind them that no one can straighten out later.

So in the process of growing up, the technique of dwarf mistletoe control has passed its infancy. We now know what to do, and have a pretty good idea how to do it. The program has matured. It is now time to demand accomplishment, and not just give it lip service.

INTERMEDIATE CUTTINGS IN MISTLETOE-INFESTED LODGEPOLE PINE AND SOUTHWESTERN PONDEROSA PINE STANDS[1]

Frank G. Hawksworth[2]

Abstract: Intermediate cuts in mistletoe-infested lodgepole pine and ponderosa pine stands include "sanitation cuttings" (where all visibly infected trees are cut) and "sanitation thinnings" (where emphasis is on spacing and cutting the trees that are most heavily infected). Sanitation cuttings are recommended only in stands where less than about 40 percent of the trees are infected. Usually such stands are less than 30 years old. Sanitation thinnings are usually applied to stands over 30 years, but are not recommended in heavily infested stands because heavily infected residual trees will show little response to thinning. Presently, we do not suggest thinning in stands with an average dwarf mistletoe rating (6-class system) of 3 or more. Yield simulation procedures are available for mistletoe-infested lodgepole pine stands in the central Rockies and for southwestern ponderosa pine.

INTRODUCTION

Intermediate cuts include all the cutting treatments made following establishment of the new stand until the time to replace it. Cuttings are made when needed, normally at specific intervals, to increase the quantity and quality of timber produced, and to salvage material which would otherwise be lost. Common intermediate cuts are: (1) thinnings, and (2) improvement cuttings, including sanitation and salvage (Myers 1974). For practical purposes here we will consider "sanitation cuttings" (where removal of all visibly infected trees is attempted) and "sanitation thinnings" (where the emphasis is on spacing and usually only the most severely diseased trees are removed).

This paper considers lodgepole pine (_Pinus_ _contorta_ Dougl. ex Loud. subsp. _latifolia_ [Engelm. ex Wats] Critchf.) stands in the central Rocky Mountains affected by the dwarf mistletoe _Arceuthobium_ _americanum_ Nutt. ex Engelm. and ponderosa pine (_P. ponderosa_ Laws. var. _scopulorum_ Engelm.) in the Southwest affected by A. _vaginatum_ (Willd.) Presl. subsp. _cryptopodum_ (Engelm.) Hawks. & Wiens.

THINNING IN UNINFESTED STANDS

Before discussing thinning in mistletoe-infested stands, it would be helpful to summarize thinning recommendations in noninfested stands, which form the basis for thinnings in diseased stands.

Lodgepole pine

The following thinning recommendations are summarized from Alexander (1974) and Cole (1975).

a. If stands have fewer than 2,500 stems per acre, thinning can be delayed until age 30 (total age).

b. If stands have more than 2,500 stems per acre, thinning should be done before age 30, ideally between ages 10 and 20, and should leave 1,200 to 1,500 stems per acre.

c. If stands have 2,500 to 4,000 stems per acre, thinning will show some reponse up until about age 70, but wider spacings should be used than in younger stands.

d. Stands with more than 2,500 to 4,000 stems per acre or more than about 70 years old generally will not recover sufficiently to cover costs of thinning

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[1] Presented at Symposium on Dwarf Mistletoe Control through Forest Management, Berkeley, Calif. April 11-13, 1978.

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Later thinning recommendations in lodgepole pine are based on the growing stock level (GSL) concept (Edminster 1978). The GSL's are numerical indices representing residual basal areas when the average tree diameter reaches 10 inches or more. In stands where average tree diameter is more than 10 inches d.b.h., GSL and basal area are the same.

Ponderosa pine

Thinning recommendations for ponderosa pine in the Southwest and in Colorado are also based on GSL (Schubert 1974, Myers 1974). The GSL recommended depends on the management objectives for the particular stand. For example, if timber volume production is the primary objective, a moderately high GSL (e.g., 100 to 120) is suggested. However, if other forest values need to be considered, such as grazing and recreation, lower levels (e.g., GSL 40 to 60) are frequently recommended).

Ponderosa pine remains physiologically young and responds to thinning up to at least 200 (Pearson 1950). However, from a practical standpoint, thinning in older stands may not be economical.

SANITATION CUTTINGS

"Sanitation cutting" as used here involves removal of all visibly infected trees in a stand, usually in conjunction with a thinning operation. In lodgepole pine and ponderosa pine, stands in which sanitation is feasible are usually less than 30 years old. In older stands, dwarf mistletoe infestation frequently develops to such an extent that removal of all infected trees would create too large openings.

An important consideration is the number of latent dwarf mistletoe plants (i.e., those overlooked in the first operation or incipient). As a guide from our studies in lodgepole pine, supported somewhat by results in other species, we developed the "half-again rule." This states that the proportion of trees infected about 5 years after an initial sanitation will be about half the amount removed in the first operation. For example, if 12 percent of the trees were infected at the time of the first operation, about 6 percent more will develop infections. This guide seems to apply to stands with up to about half of the trees infected before the first sanitation.

Interim results from sanitation cuttings in young lodgepole pine stands provide some guides (Baranyay 1975, Hawksworth et al. 1977). The degree of infestation in the stand, not strictly stand age, is the best criterion to decide whether sanitation is practical. A general guide is that stands with more than about 40 percent of the trees infected are too heavily infected to attempt strict sanitation cutting (removal of all infected trees). In such stands, the large numbers of reinfected trees would necessitate removal of so many trees that stocking would be seriously reduced. In these studies, all of the 20-year-old, and most of the 30-year-old stands had fewer than 40 percent of the trees infected. Most of the 40-year-old stands had more than 40 percent of the trees infected, but in the one that had less than 20 percent infestation, sanitation appears to have been successful.

SANITATION THINNINGS

It wasn't too many years ago that to recommend any thinning in mistletoe-infested stands would have been considered to be the height of folly. For years, I was a strong advocate of the "no-thinning" philosophy. When I began working on dwarf mistletoes in the Southwest in the early 1950's, I was shown several infested stands that had been thinned some 15-20 years previously. These stands were real "disaster areas" and they made quite an impression on me. The ground in these stands was jackstrawed with the carcasses of mistletoe-killed trees and the few surviving trees were so severely infested that their days, too, were numbered. The theory was that the increased light in thinned stands stimulated the parasite, so it was able to rapidly intensify and kill the residual trees. Obviously the only answer was not to thin in infested stands.

But, as I began to examine other thinnings in infested stands, both in ponderosa pine in the Southwest and in lodgepole pine in the central Rockies, I noticed there were some stands that did not break up after thinning, but rather, seemed to be growing more volume than before.

We still don't know why thinnings are successful in some stands and not in others, but we think that at least two important factors are involved: (1) the degree of infestation in the stand, and (2) site quality.

The present evidence suggests that thinnings in infested stands can increase volume increment, provided infection is not too heavy. It is not known where this cutoff line is, and how it varies with type of stand, age class, or site quality. For example, we think that effects of dwarf mistletoe are site-related;

that is, a given degree of infection will have relatively less effect on growth on a good site than on a poor one. However, mistletoe incidence frequently is not site-related. For example, the dwarf mistletoes occur on the best lodgepole pine sites that we have seen in the Central Rockies and on the best ponderosa pine sites in the Southwest, but their effects on these good sites are relatively insignificant.

At present, we do not recommend thinning in stands that have an average dwarf mistletoe rating ($\overline{\text{DMR}}$) of 3.0 or more (6-class system, Hawksworth 1977). This may seem rather low, but as shown in figure 1, about 90 percent of the trees in such stands are infected, leaving relatively few uninfected or lightly infected trees to work with. We recommend removal of as many infected trees as possible without creating large openings. Usually, trees with a DMR of 4 or higher should not be retained. It is better to sacrifice some spacing to remove such heavily infected trees, since they will usually show little growth response after thinning.

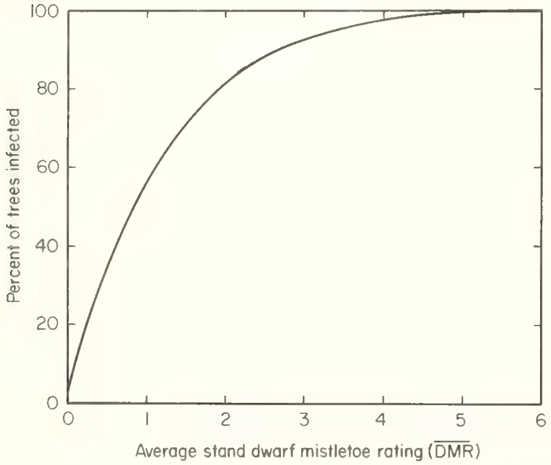

Figure 1--Relationship between percent of trees infested and average stand dwarf mistletoe rating ($\overline{\text{DMR}}$) for lodgepole pine stands.

Dwarf mistletoe levels in residual trees should be low in young stands because it will be many years before they are of merchantable size. Conversely, higher levels can be left in older stands, since they will be harvested before the mistletoe levels increase to damaging proportions.

At present, there are no "hard and fast" rules to determine whether sanitation thinning will help a particular stand. Each stand must be analyzed considering the: (1) protected yields, (2) market conditions, and (3) economics Research can now provide information only on the first, using simulated yield projections.

Yield projections for mistletoe-infested stands have been published for even-aged lodgepole pine in the central Rocky Mountains (Myers et al. 1971) and for even-aged and two-storied ponderosa pine in the Southwest (Myers et al. 1976, Edminster and Hawksworth 1976). These are being adapted and tested on other areas and for other host-parasite combinations.

Using these programs on a stand basis, the forest manager can examine many options for a very low cost and then decide on the treatment that will give maximum yields commensurate with management objectives for the area. For example, he can compare cubic feet vs. board feet yields. He can examine such options as: (1) do nothing, (2) thin to various growing stock levels, (3) thin at various intervals, and (4) delayed thinnings. Also, he can compare yields in infested stands with uninfested stands to determine potential yields on the site.

Examples from the lodgepole pine program are given from two stands in the Routt National Forest in northern Colorado (tables 1-3).

Table 1 shows the projected yields in relation to GSL. In this case, if the stands are not treated, after 100 years, we can expect no board feet volume, since the trees will not reach the 6.5 inches minimum stand diameter. After 100 years, thinning to GSL 70 will yield about 15,200 board feet per acre and to GSL 90 about 16,600 feet. In general, higher GSL's yield more volume in uninfested stands; the converse is true for moderately to heavily infested stands. In this case, higher GSL results in higher project yields, presumably because mistletoe was relatively light (only 27 percent of the trees infected). Table 2 shows an analysis of cutting cycles in the same stand. Examining just three alternatives shows that cutting cycles at 30-year intervals will increase both merchantable and board feet yields

Table 1--Effects of growing stock level (GSL) on simulated yields in a 30-year old lodgepole pine stand, Porcupine Creek, Routt National Forest, Colorado. Present stand conditions: avg. d.b.h. - 2 inches, Site Index - 60, trees per acre - 2,680, and percent of trees infested - 27.

	100-year yield/acre	
Treatment	Merchantable cubic feet	Board feet
None	2,460	0
Thin GSL 70 (30-year intervals)	3,290	15,200
Thin GSL 90 (30-year intervals)	3,810	16,600

Table 2--Effects of length of cutting cycle (at GSL 90) on simulated yields in a 30-year old lodgepole pine stand, Porcupine Creek, Routt National Forest, Colorado. Present stand conditions: avg. d.b.h. - 2 inches, Site Index - 60, trees per acre - 2,680, and percent of trees infested - 27.

	100-year yield/acre	
	Merchantable cubic feet	Board feet
None	2,460	0
Thin 30-year intervals	3,810	16,600
Thin 50-year intervals	3,510	14,700

Table 3 shows an older stand (age 70 years which is generally considered to be near the upper limit of thinning feasibility. However, even in this case, we can see a market improvement by thinning. The stand, if left alone, will not yield merchantable or board feet volume because the trees will not reach the average 6.0 and 6.5 inches, respectively, for calculation of these volumes. Thinning can yield 9,000-10,000 board feet per acre after 60 years.

Table 3. Effects of one vs. two thinnings (at GSL 90) on simulated yields in a 70-year old lodgepole pine stand, Snyder Creek, Routt National Forest, Colorado. Present stand conditions: avg. d.b.h. - 3 inches, Site Index - 55, trees per acre - 4,330, and percent of trees infested - 34.

	60-year yield/acre	
Treatment	Merchantable cubic feet	Board feet
None	0	0
Thin age 70 and 100; harvest age 130	2,350	9,000
Thin age 70; harvest age 130	2,930	9,900

To estimate the relative effects of dwarf mistletoe in ponderosa pine and lodgepole pine, yield simulations were made for the same hypothetical stand conditions: present stand age - 30; average d.b.h. - 3 inches; density - 1,000 stems per acre; Site Index - 40, 60, and 80; and mistletoe infection - none, or 50 percent of trees infected. Projections were made for 90 years (until stand age 120) assuming (1) no thinning, and (2) thinning to growing stock levels 60, 80, and 100 at ages 30, 60 and 90.

Some of the results are given in Table 4 for lodgepole pine and in Table 5 for ponderosa pine. Thinning to GSL 100 is shown for these examples only. Some of the results of these analyses are:

1. For noninfested stands, increased yields per acre due to thinning are about the same regardless of Site Index, but the proportion of the increase is much higher on poorer sites.
2. For a given amount of infection, assuming the same stand treatments, dwarf mistletoe losses are significantly greater in ponderosa pine than in lodgepole pine.
3. If infested stands are not thinned, the cubic foot losses are greater on site 80 than on site 40, but the proportional loss is greater on the lower sites. For example, in the case cited for lodgepole pine in Table 4, the volume in the infested stand was 64 percent of that of the uninfested stand in site 40, but the

Table 4--Simulated 90-year yields in lodgepole pine stands now 30 years old. Average d.b.h. = 30 inches, 1,000 trees per acre. Treatment stands thinned at age 30, 60, and 90.

		Merchantable cubic foot volume acre site index		
Stand Condition	Treatment	40	60	80
No mistletoe	None	1,490	5,220	8,610
	thin GSL 100	2,680	5,530	9,610
	Difference			
	cubic feet	+1,190	+ 310	+1,000
	percent increase	180	106	112
50% trees infected ($\overline{\text{DMR}}$ = .07)	None	960	3,840	7,240
	thin GSL 100	2,490	5,420	9,310
	Difference			
	cubic feet	+1,530	+1,580	+2,070
	percent increase	259	141	129
Uninfected vs. 50% trees infected	None			
	Difference			
	cubic feet	- 530	-1,380	-1,370
	percent decrease	64	74	84
Uninfected vs. 50% trees infected	Thin GSL-100			
	Difference			
	cubic feet	- 190	- 110	- 330
	percent decrease	93	98	97

comparable figure on site 80 was 84 percent.

4. For a given site index, the relative gains due to thinning (e.g., yields in thinned stands/yields in unthinned stands) increase as dwarf mistletoe intensity increases. For example, in lodgepole pine, on site 60, increase in yields due to thinning in stands with only 10 percent of the trees infected is only about 6 percent (essentially the same as for noninfested stands), but in stands with 50 percent of the trees infected, yields are increased by 40 percent.

Table 5--Simulated 90-year yields in ponderosa pine stands now 30 years old. Average d.b.h. = 3.0 inches, 1,000 trees per acre. Treated stands thinned at age 30, 60, and 90.

		Merchantable cubic foot volume acre site index		
Stand Condition	Treatment	40	60	80
No mistletoe	None	1,840	4,180	6,480
	thin GSL 100	2,570	4,640	7,280
	Difference			
	cubic feet	+ 770	+ 460	+ 800
	percent increase	143	111	112
50% trees infected (DMR = 0.8)	None	170	740	2,670
	thin GSL 100	850	2,630	6,240
	Difference			
	cubic feet	+ 680	+1,890	+3,570
	percent increase	500	355	234
Uninfected vs. 50% trees infected	None			
	Difference			
	cubic feet	- 1670	-3,440	-3,810
	percent decrease	9	18	41
Uninfected vs. 50% trees infected	Thin GSL-100			
	Difference			
	cubic feet	-1,720	-2,010	-1,040
	percent decrease	33	57	86

CONCLUSIONS

Many studies have shown that dwarf mistletoes are stimulated by opening up stands by thinning. However, it has not been determined whether this is due to increased light or to improved tree vigor of the residual trees, or, as I suspect, to a combination of both factors. We also know that the effects of dwarf mistletoe are less pronounced in more vigorous trees, so the beneficial effects of thinning will be evident in increased growth rates, despite the fact that mistletoe might also increase. However, thinning can not be recommended in heavily infested stands. We do not know exactly when a given stand is too heavily infested to thin, but we tentatively suggest that thinning be confined to stands with a DMR of 3 or less.

Although these are some guides to help determine whether a given infested stand should be thinned or not, each stand must be evaluated on an individual basis.

We don't know how close our projections are to actual yields, except that our data are based on actual stands and should be reliable. Some pathologists and foresters think that we are overestimating losses, others think we are underestimating them, so perhaps we are on the right track. To monitor the effects of thinning in dwarf mistletoe infested stands, we are establishing a series of plots in infested lodgepole pine stands in Colorado and in ponderosa pine in Colorado and Arizona. Stands with various intensities of dwarf mistletoe (including mistletoe-free stands) are being thinned to several GSLs. Periodic examination of the plots will show how close our projections are to the actual yields and will provide data for adjusting growth and mistletoe-effects equations as needed.

LITERATURE CITED

Alexander, Robert R.
1974. Silviculture of subalpine forests in the central and southern Rocky Mountains: The status of our knowledge. USDA For. Serv. Res. Pap. RM-121, 88 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Baranyay, J. A.
1975. Dwarf mistletoe as a factor in the management of lodgepole pine forests in western Canada. Management of lodgepole pine ecosystems. Symp. Proc. Wash. State Univ., D. A. Baumgartner, editor. Vol. 1: 359-367.

Cole, Dennis M.
1975. Culture of immature lodgepole pine stands for timber objectives. Management of lodgepole pine ecosystems. Symp. Proc. Wash. State Univ., D. A. Baumgartner, editor. Vol. 2:536-555.

Edminster, Carleton B.
1978. RMYLD: Computation of yield tables for even-aged and two-storied stands. USDA For. Serv. Res. Pap. RM-199, 26 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Edminster, Carleton B., and Frank G. Hawksworth
1976. User's guide to SWYLD2: Yield tables for even-aged and two-storied stands of southwestern ponderosa pine, including effects of dwarf mistletoe. USDA For. Serv. Gen. Tech. Rep. RM-23, 8 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins Colo.

Hawksworth, Frank G.
1977. The 6-class dwarf mistletoe rating system. USDA For. Serv. Gen. Tech. Rep. RM-48, 7 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Hawksworth, F. G., T. E. Hinds, D. W. Johnson, and T. D. Landis
1977. Silvicultural control of dwarf mistletoe in young lodgepole pine stands. USDA For. Serv., Rocky Mt. Reg., For. Insect and Disease Manage. Tech. Rep. R2-10, 10 Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Myers, Clifford A.
1974. Multipurpose silviculture in ponderos pine stands of the Montane Zone of central Colorado. USDA For. Serv. Res. Pap. RM-13 15 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Myers, Clifford A., Frank G. Hawksworth, and James L. Stewart
1971. Simulating yields of managed, dwarf mistletoe-infested lodgepole pine stands. USDA For. Serv. Res. Pap. RM-72, 15 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Myers, Clifford A., Carleton B. Edminster, and Frank G. Hawksworth
1976. SWYLD2: Yield tables for even-aged and two-storied stands of southwestern ponderosa pine, including effects of dwarf mistletoe. USDA For. Serv. Res. Pap. RM-163, 25 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Pearson, G. A.
1950. Management of ponderosa pine in the Southwest. U. S. Dep. Agric. Monogr. 6, 218 p.

Schubert, Gilbert H.
1974. Silviculture of southwestern ponderos pine: The status of our knowledge. USDA For. Serv. Res. Pap. RM-123, 71 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

ECOLOGICAL BASES FOR SILVICULTURAL PRESCRIPTIONS FOR CONTROL OF DWARF MISTLETOE IN LODGEPOLE PINE[1]

Phil Guthrie[2]

Abstract: Preparation of silvicultural prescriptions is a complex process in lodgepole pine ecosystems. Ecological factors and management decisions must be considered. The presence or absence of dwarf mistletoe in a stand is one ecological factor that must be considered. Control of dwarf mistletoe is possible through application of sound silvicultural principles.

Key Words: Silvicultural prescriptions; dwarf mistletoe control; Arceuthobium americanum; Pinus contorta.

SILVICULTURE AND ECOLOGY

Silviculture has been defined as "the art and science of growing trees". The art of growing trees refers to management of trees by instinct, "gut feelings" and at times flying by the seat of our pants. There always has been and probably always will be a place in silviculture for this art which comes from familiarity with a given ecotype and experience in how the ecotype reacts to a given type of treatment. The art should not, however, be our dominant form of management.

The science of growing trees is plant ecology.

Past management efforts by foresters often placed much more emphasis on the art than on the science. There are many reasons for this, but the main ones are: 1) The difficulty of remaining professionally current in a field as diverse as forestry; and, 2) The lack of time to prepare prescriptions that analyze and document the bases for management actions.

This reliance on the art rather than the science of stand management resulted in some stand treatments in lodgepole pine (Pinus contorta Dougl.) that were ecologically questionable and/or socially insensitive.

Adverse public reaction to large clearcuts and drastic site preparation and brush disposal methods necessitated some change in our ways of treating stands. It soon became obvious that it was time to rely more on the sciences of forest and plant ecology than on the art of growing trees.

SILVICULTURAL PRESCRIPTIONS

Reasons for Silvicultural Prescriptions

All of our research, education, training and experience are of little value if they are not eventually expressed in on-the-ground treatments. The silvicultural prescription provides the medium for translating this knowledge into a plan of action. Northern Region Guidelines for Development of Silvicultural Prescriptions list four basic purposes of a prescription:

1. The prescription provides a logical method of analysis of a stand to determine alternative cultural treatments. The prescription will also assist in the evaluation of the environmental impact of such treatments.
2. The prescription provides direction for carrying out cultural treatments.
3. The prescription documents the scientific basis for the alternative treatments.
4. The prescription is a record that allows for later evaluation of the effectiveness of the cultural treatments (Anon. 1976).

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Uses of Standard Prescriptions

We used to prescribe treatments that were considered as standard for certain tree species in a given locality. Examples of these might include "clearcut, burn, and plant white pine" in northern Idaho; "thin to favor larch" in western Montana; and "the bigger the better" when referring to clearcuts in dwarf mistletoe--(Arceuthobium americanum Nutt. ex. Engelm.) infected lodgepole pine. Each region, state and private company has used standard prescriptions.

The more you prescribe treatment for various stands, the more evident it becomes that these standard prescriptions are no longer acceptable. Complex ecosystems require more in-depth analysis than can be applied through standard treatments. This is true even in lodgepole pine type, which appears to be both consistent and monotonous. Lodgepole pine has been identified in 82 habitat types or phases of habitat type in Montana alone (Pfister et al. 1977). Lodgepole pine is one of the most widespread tree species in western North America. The capacity of lodgepole to grow in such a variety of environments over such a broad geographic area is surpassed by few other conifers in North America (Critchfield 1957, Tackle 1961, 1965). Pfister and Daubenmire noted that lodgepole pine occurs in 166 of 264 identified forest habitat types, community types, sample stands, forest zones, forest associations, site types and biogeoclimatic zones, from the central and northern Rockies and the Inland Empire in the United States northward into Alberta and British Columbia in Canada (Pfister and Daubenmire 1975).

The broad ecological amplitude indicates that lodgepole pine is a more complex ecological entity than is often recognized.

Management Direction

Silvicultural prescriptions must state clearly how treatments will meet management direction as defined in the land use planning process or as expressed by land managers (Anon. 1976).

In the Forest Service, this involves an interdisciplinary team. The manager (Forest Supervisor or District Ranger) with input from the team, resolves any conflict between competing resource uses on the same piece of ground and establishes the management direction for a large area.

It is then up to the silviculturist to prescribe an ecologically sound treatment that meets the management goals for a particular timber stand.

Primary Prescription Elements

The Northern Region has identified seven elements all-inclusive that must be included in a silvicultural prescription (Anon. 1976):

1. Objectives - After obtaining the land management objectives, the silviculturist defines silvicultural objectives which satisfy management objectives.

2. Site Data - Slope, aspect, elevation, physiographic site, landform, geology, soils, climate, habitat type and relative productivity are described. Areas of potential resource damage or conflict are identified. These areas include streams, bogs, frost pockets, areas of concentrated wind, critical big-game habitat, or landscape management features.

3. Stand Data - These data include species composition, stand structure by age as well as size class distribution, density, stand history and successional trend, true crown condition, growth rates, timber volumes, and understory conditions. The status of insects and diseases (including dwarf mistletoe), windthrow hazards, estimates of fuel loadings within and around the stands, and factors affecting slash disposal, site preparation or regeneration are discussed.

4. Treatment - The treatment to be applied at this stand entry is described. This description is detailed enough so that marking guides or other pertinent preparation guides can be written from it. Some of the details discussed include the following:

    a. Type of treatment: (1) Timber Cutting: What type silvicultural system is to be applied; intermediate, salvage or regeneration cut? What method of the system is to be applied? The composition and density of the resultant stand must be indicated. (2) Site Preparation: What method is to be applied and to what degree? (3) Reforestation: What method is planned? What species and stocking level is desired? When is the desired stocking level to be achieved?

b. Logging method proposed - Silviculturists are not logging systems specialists, but they must be aware of the capabilities of the various logging systems to meet the silvicultural objectives of the prescribed treatment.

c. Methods for hazard reduction and protection to a manageable understory.

d. Insect and disease protection and/or control. So far I have said little about dwarf mistletoe or its impact on timber stands. There are numerous examples of stands which were treated without regard to the presence of dwarf mistletoe. These treatments almost invariably have serious long term impacts on stand productivity. Susceptibility of the stand to insects and other diseases must also be considered. In the case of lodgepole pine, if the stand is of the size, vigor, phloem thickness and age to be highly susceptible to attack by the mountain pine beetle (Dendroctonus ponderosae Hopkins), a final removal should be prescribed in the near future or anticipated losses should be documented (Amman 1975). The prescription must consider presence of, and stand susceptibility to, insects and diseases.

e. Effect of the treatment on the site. The effect of the treatment on the basic site resource must be evaluated. For example, site productivity can be drastically reduced through compaction of soils if the soils are of a type highly susceptible to compaction (silts or silt loams). In stands where organic matter is a scarce component within the surface soil horizons, drastic site preparation, either by burning or by machine, can drastically reduce site productivity. The same may be true on well-drained, deep soils in areas of moderate to high rainfall, where nutrient loss through leaching of bare soil may contribute to site degradation.

f. Genetic implications of the treatment. Gains in tree improvement in the near future will be far more dramatic from application of genetically sound silvicultural prescriptions than from controlled breeding programs. This will be true throughout most of the west for the next several years because acreage reforested with certified improved seed or planting stock will be small compared with the total acreage reforested. Natural regeneration will continue to play the major role in reforestation efforts in the West. Gains in genetic quality of stands will be of two types: The quality of parents that are selected for the next generation; and the constant selection of superior phenotypes as crop trees in intermediate stand entries.

g. Effect of the treatment on wildlife populations. Interactions between wildlife and silvicultural treatments can be a two-edged sword. Silvicultural stand entries may improve the habitat for some wildlife species at the same time they degrade the habitat for others. In stands critical to the survival of important wildlife herds, silvicultural treatment may need to be deferred or foregone. On the other hand, game animals, rodents, and birds can be extremely damaging to young tree regeneration (Lawrence 1961, Lindsey 1975).

h. Effect of the treatment on use of the area by man, his visual and other values. Recreational use of the National Forests has greatly increased the demand for amenities such as natural beauty, solitude and opportunities for dispersed recreation. A prescription must evaluate the demands for and impacts on these amenities created by the proposed treatment.

i. Needs and possible methods for livestock use and control. Livestock, like wildlife, can be extremely damaging to reproduction. A prescription must analyze whether or not livestock needs to be controlled, anticipated damage, and methods for protection of regeneration.

5. Long Term Prescription - Treatments applied to timber stands today will affect future management at least until the next regeneration cut. The genetic impacts of today's treatments may last for two or more rotations. A silviculturist should consider these long range implications and project stand treatments and returns from the present through the next regeneration period. Anticipated growth and yield due to the prescribed treatments should be analyzed as well as anticipated

losses to insects, diseases, and wildfire.

6. Economic Comparisons - All prescriptions should include a brief economic analysis comparing returns on the investment prescribed with deferred action and other possible alternatives.

7. Alternatives - Viable alternatives should be described briefly. Deferred treatment should be one of the alternatives considered. Reasons for not recommending each alternative should be given.

IMPACTS OF ECOLOGICAL FACTORS AND MANAGEMENT OBJECTIVES ON CONTROL OF DWARF MISTLETOE IN LODGEPOLE PINE

Preparation of a silvicultural prescription involves consideration of the ecosystem, management direction, and impacts of prescribed treatments. It is an involved process similar to working through a complex maze. There are many ways in which the analysis can affect our efforts to control dwarf mistletoe in lodgepole pine. First let's review our options.

Use of Silvicultural Systems to Control Lodgepole Pine Dwarf Mistletoe

Control does not mean eradication (Hawksworth 1975). The incidence of dwarf mistletoe in future managed stands will be negligible and growth losses will be immeasurably small. Eradication is neither feasible nor desirable.

In order to accomplish control, it is essential to know the location and extent of infected areas. A well designed stand examination can identify and map infected areas.

After the examination, a prescription is then prepared, taking into account the ecological and management bases previously discussed.

The soundest and most feasible control practice is to protect young stands and prevent the invasion of uninfected stands from adjacent infected ones (Baranyay 1975, Hawksworth 1975). If the stand is heavily infected, it should be sanitized and regenerated by using one of these three silvicultural systems:

1. Clearcutting - Eradication of the existing stand, followed by regeneration is the simplest and usually cheapest method of control. This is done by cutting merchantable trees, followed by site preparation and slash disposal and finally removing any remaining "whips" or small trees. Clearcutting more nearly appraoches the natural system of regenerating lodgepole pine than any other system.

2. Shelterwood - The shelterwood system can also be used to regenerate lodgepole pine. Some considerations are:
    a. Is it needed for ecological or management purposes?
    b. What is the danger of windfall?
    c. How will leaving the shelterwood volume affect the economic feasibility of a commercial sale?
    d. How long can the shelterwood be held on the stump without seriously infecting the regenerated stand?

    The shelterwood system is useful in regenerating species that need only partial sunlight for germination and establishment (Smith 1962). It is also useful on harsh sites. Overuse of the system to blunt the visual impact of clearcutting must be avoided, however. In substituting shelterwood cuts for clearcuts, we run the risk of cutting larger acreages to meet volume goals. In a few years, we may find that the regeneration is not tall enough to ameliorate the visual or environmental impacts caused by shelterwood removal. By removing the shelterwood, we have created the same condition we would have had in a regenerated clearcut.

    The shelterwood system can be useful in lodgepole pine if management or environmental constraints do not allow clearcutting, if there is sufficient volume after the shelterwood is left to make a viable timber sale, if the danger of windfall is low, and if the shelterwood is removed before it infects the regeneration.

    The seed cut must be followed by sanitation of the stand through eradication of residual stems during or immediately following slash disposal and site preparation.

3. Seed-Tree - The same considerations

apply to the seed-tree system as to the shelterwood system. Cone serotiny is a factor in determining numbers of seed trees necessary to regenerate a stand. Most seed from nonserotinous cones is disseminated within 200-300 feet of the parent tree (Tackle 1961, 1965). This means that a minimum of 1 to 1-1/2 trees per acre is necessary to seed the cutover area.

The seed-tree system can be useful in regenerating lodgepole pine if the same conditions are met as with the shelterwood system.

4. Selection - The selection system is generally not applicable to lodgepole pine. In dwarf mistletoe-infected stands, the selection system creates conditions most favorable to spread and intensification of the parasite. There is one area on the Gallatin National Forest near West Yellowstone, Mont., where application of the system appears possible.

The soils around West Yellowstone are composed of obsidian sands of alluvial origin (Pfister et al. 1977). Lodgepole pine is climax. The habitat type is lodgepole pine/bitterbrush. Apparently, the sites are too frosty to support Douglas-fir and too dry (excessively well drained) for subalpine fir or Englemann spruce (Pfister et al. 1977). Stands vary from moderately dense to moderately open. The stands are not all aged but are definitely uneven aged. Dwarf mistletoe-infected areas are well defined and mappable (Dooling et al. 1977).

Numerous clearcuts, some quite large, have contributed to these management decisions. The area receives very heavy recreation use because of its proximity to Yellowstone National Park. Therefore, any additional even-aged regeneration cuts should be designed with small blocks and irregular boundaries.

Uninfected stands could be used to break up the effect of the clearcut blocks, and may be harvested using individual tree and group selection. Use of this combination enables sale of timber in an area where clearcutting of comparable volumes or acreages would no longer be acceptable.

5. Intermediate Cuttings - Hawksworth has described, in this symposium, the effects of intermediate entries into dwarf mistletoe-infected lodgepole pine stands so I will not dwell on the subject. There are two concepts that have worked well for me that I would like to discuss.

Some stands that are predominantly lodgepole pine have an understory of lodgepole pine plus more tolerant species. Nonhost trees often make up a large proportion of the residual stand. If the dwarf mistletoe infection level in the lodgepole pine reproduction is low to moderate (infection levels 1-3) (Hawksworth 1977) and if the regeneration of the tolerant species is manageable, leaving as many of the tolerant trees as possible will lessen the impact of scattering dwarf mistletoe-infected lodgepole pine. This does not mean that we manage advanced regeneration that is composed of moderately to heavily infected (infection classes 4-6) (Hawksworth 1977) lodgepole pine or badly suppressed tolerant trees with little or no hope of release.

The concept is to remove all moderately to heavily infected lodgepole pine and favor healthy, vigorous nonhost species.

Some indicators of manageability in subalpine fir and spruce advanced regeneration include:

a. Good current height growth. It is not reasonable to expect trees under an overstory to grow at the same rate that they would in a free growing condition. In eastern Montana, trees that have been growing six inches or more in height annually for the past several years and appear healthy and vigorous will probably release with overstory removal and thinning.

b. Age. Guidelines for the Central Rockies suggest that 50 years for subalpine fir and 75 years for spruce are the maximum ages to expect response to release and thinning (Roe et al. Undated).

c. Absence of disease or injury. Diseased or injured trees of tolerant species, particularly true firs are not good risks as crop trees.

This concept should be applied only by silviculturists experienced in the management of the species involved and familiar with local variations. If a District Ranger or silviculturist uses this discussion to justify trying to manage a 100 year old, badly suppressed true fir stand that has little hope of survival, much less release, they have missed the point.

The second concept that I would like to stress is that dwarf mistletoe should be discriminated against at every stand entry. This does not mean that "the only good dwarf mistletoe-infected tree is a dead one," but it does mean that infection class is one of the strongest selection criteria in intermediate stand entries.

LITERATURE CITED

Amman, Gene D.
1975. Insects affecting lodgepole pine productivity. In Management of lodgepole pine ecosystems. Vol. 1. David M. Baumgartner, ed. Coop. Ext. Serv., Coll. Agric., Washington State Univ., Pullman, Wash., 495 p., illus.

Anonymous.
1976. Forest Service Manual 2478.3. Region 1 Supplement 190. U.S. Dep. Agric., Forest Serv., Northern Region, Missoula, Mont.

Baranyay, J.A.
1975. Dwarf mistletoe as a factor in the management of lodgepole pine forests in Western Canada. In Management of lodgepole pine ecosystems. Vol. 1, David M. Baumgartner, ed. Coop. Ext. Serv., Coll. Agric., Washington State Univ., Pullman, Wash. 495 p., illus.

Critchfield, W.B.
1957. Geographic variation of Pinus contorta. Maria Morrs Cabot Found. Publ. 3, Harvard Univ., Cambridge, Mass.

Dooling, Oscar J., J.D. Bortz, and M.W. Maxwell.
1977. Dwarf mistletoe survey, Hebzen Lake Ranger District, Gallatin National Forest, Montana. U.S. Dep. Agric. Forest Serv., Northern Reg. Rep. 77-13, 5 p. Missoula, Mont.

Hawksworth, Frank G.
1977. The 6-class dwarf mistletoe rating system. U.S. Dep. Agric. Forest Serv., Gen. Tech. Rep. RM-48, 7 p. Rocky Mountain Forest and Range Exp. Stn., Fort Collins, Colo.

Hawksworth, Frank G.
1975. Dwarf mistletoe and its role in lodgepole pine ecosystems. In Management of lodgepole pine ecosystems. Vol. 1, David M. Baumgartner, ed. Coop. Ext. Serv., Coll. of Agric., Washington State Univ., Pullman, Wash. 495 p., illus.

Hawksworth, Frank G.
1972. Biology and classification of dwarf mistletoes (Arceuthobium). U.S. Dep. Agric., Agric. Handb. 401, 234 p., illus.

Lawrence, William H.
1961. Guide to wildlife feeding injuries on conifers in the Pacific Northwest. West. For. and Conserv. Assoc., Portland, Oreg., 44 p., illus.

Lindsey, Gerald D.
1975. The influence of animals on lodgepole pine regeneration. In Management of lodgepole pine ecosystems. Vol. 1, David M. Baumgartner, ed. Coop. Ext. Serv., Coll. Agric., Washington State Univ., Pullman, Wash. 495 p., illus.

Pfister, Robert D., Bernard L. Kovalchik, Stephen F. Arno, and Richard C. Presby.
1977. Forest habitat types of Montana. U.S. Dep. Agric. Forest Serv. Gen. Tech. Rep. INT-34, 174 p., illus. Intermountain Forest and Range Exp. Stn., Ogden, Utah.

Pfister, Robert D., and R. Daubenmire.
1975. Ecology of lodgepole pine. In Management of lodgepole pine ecosystems. Vol. 1, David Baumgartner, ed. Coop. Ext. Serv., Coll. Agric., Washington State Univ., Pullman, Wash. 495 p., illus.

Roe, Arthur L., Robert R. Alexander, and Milton D. Andrews.
(Undated) Engelmann spruce regeneration practices in the Rocky Mountains. U. S. Dep. Agric. Forest Serv. Prod. Res. Rep. 115, 32 p.

Smith, David M.
1972. The continuing evolution of silvicultural practice. J. For. 70:89-92.

Smith, D. M.
1962. The Practice of Silviculture. 7th Ed. John Wiley and Sons, Inc., New York, New York. 578 pp. illus.

Tackle, D.
1965. Ecology and Silviculture of Lodgepole Pine. Proc. S.A.F. Meeting 1964:112-115.

Tackle, D.
1965. Silvics of Lodgepole Pine. U.S.D.A. Forest Service, Intermountain Forest and Range Exp. Station Misc. Publication 18. 24 pp. (revised).

DWARF MISTLETOE CONTROL IN RESIDENTIAL FORESTS[1]

John G. Laut[2]

Abstract: Residential forests -- where forests are maintained primarily for their effects on people -- present unique problems and opportunities for control of dwarf mistletoe. Five case studies are presented to demonstrate feasibility of pruning-thinning treatments in these situations.

INTRODUCTION

One spin-off from the environmentalist movement of recent years has been an increased public awareness of trees and their values. All through the West and, especially in Colorado, the forest resource is coming under tremendous people-pressure. These people demand answers to questions about tree management -- not necessarily forest management. Questions arise, in the biological fields dealing with tree diseases, insects and physiology, that forest pathologists, entomologists and silviculturists can't easily answer.

Forest entomology and pathology, however, do have much background expertise that can be useful in managing people-stressed vegetation. Compared to traditional forest management and forest pathology, the realities of heavy people-pressures present new problems with new dimensions that demand new potential solutions. In forest pathology and entomology control development and research direction have been largely dictated by forest economics. Control must be economically feasible, but in this new field, with new values based on individual trees, the chief criterion is now biological feasibility. With these new values, if a treatment method is biologically feasible, it is very likely to be economically feasible. Under the more stringent economics of commercial forestry how many forest diseases have been controlled? The opportunities to effect control in residential forestry, on single trees or small stands that now have extremely high values, are essentially unlimited. Our customers in residential forests cry for a way to "save my tree." No method should be discarded because of so-called economic unfeasibility based on traditional forestry practices.

For purposes of definition, residential forests are those areas on which trees are maintained primarily for their effects on people. This definition requires attention to trees on city streets, yards and parks -- urban trees in the true sense -- as well as to trees in the forest where people have chosen, or are choosing, to live. The forest resource of Colorado is under tremendous people-pressure. Pathologists and entomologists are also under heavy people-pressure as a result of a developing tree-awareness in both the forests and the cities.

The human foot is trampling the forest floor; construction damage, drainage changes, and chemical additions to soil, water and air rapidly create sick trees, both in their own right and by enhancing the syndromes of existing but hitherto latent pathogenic situations. An example of this is dwarf mistletoe. Trees with non-lethal infections, or at least not immediately in danger of dying, are particularly susceptible to additional stress. As soon as someone builds a house under or near such a tree it very soon may die. Trees on extremely poor sites, as many of our Colorado East Slope ponderosa pine sites are, suffer from any additional stresses put on them.

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[1] Presented at the Symposium on Dwarf Mistletoe Control Through Forest Management, Berkeley, Calif. April 11-13, 1978.

[2] Staff Forester, Insect and Disease Division, Colorado State Forest Service, Colorado State University, Fort Collins, Colo. 80523.

Where does this lead us? Just as the discovery of Dutch elm disease can lead to a tree awareness in the city dweller, the fading of a pine tree shading his new forest home awakens the forest resident to some new facts of life. You may be tempted to say that we have always had people living in the forests and trees have always died so what is new? What is new is the type of resident. The older resident was there most likely through necessity -- his livelihood came from the forest, one way or another. The new resident very often is there by choice. The trees are part of his investment and even can be the reason behind his choice. Each tree is important. Couple this personal awareness with the overall concern for the environment that has developed in the last decade and the result is concern for trees -- not necessarily forests, but trees!

Does this field belong to foresters or to horticulturists? The answer is both if both want it. If one defaults the other will carry it completely. I believe the forestry profession cannot afford to default.

Some examples of our experiences in Colorado will illustrate my thesis that forest pathologists can and should fill a role in residential forestry.

Dwarf mistletoes, especially *Arceuthobium vaginatum* subsp. *cryptopodum* (Engelm.) Gill on ponderosa pine and *A. americanum* Nutt. ex Engelm. on lodgepole pine cause the most destructive diseases in the Rocky Mountain area. Traditional forest management of these diseases is based on silvicultural systems -- thinning, clearcutting, and so forth, aimed at rejuvenation of stands to increase growth rate. Our forest resident, however, is little concerned with production or how fast his trees grow. He wants to keep each tree alive. A tree for tree's sake!

We have established several test areas in Colorado to demonstrate that, in relatively small, high value areas within the general infestation areas, protection of those values can be accomplished by very selective cutting and by pruning of individual trees.

CASE 1

Trail West Village is a subdivision located at the foot of the Collegiate Range four miles west of Buena Vista. It lies in the transition zone between the ponderosa pine and the pinon-juniper cover types with the majority of the area in the ponderosa. Residential lots, one to three acres each, were laid out in clusters of three to five acres with dedicated "green-belts" or natural strips of varying sizes between the clusters.

In 1970 the resident manager of Trail West, recognizing that something was "wrong" with the ponderosa pine on the property, requested advice from the Colorado State Forest Service District Forester. Subsequent examination of the area led to the recommendation to control dwarf mistletoe *Arceuthobium vaginatum* subsp. *cryptopodum* in the green-belts by cutting severely infected and pruning the more lightly infected trees. This recommendation, predicatably, was received rather cooly and with some apprehension and misunderstanding -- you want to log our beautiful forest?

Continuing discussions led to agreement by the subdivision management to establish a small demonstration area in one of the greenbelts to show the residents what the area would look like, and to determine the trees' response to treatment. We were to do the work and residents of the area would clean up the logs and slash.

An area was selected and two adjacent plots were laid out at the edge of a heavily infected pocket, so that one plot was lightly infected and the other in heavily infected portions of the pocket. Stand characteristics for each plot are shown in table 1. In each plot, every tree was examined, given a dwarf mistletoe rating (DMR)[1/] from 0-6, DBH was measured and recorded and a decision made whether to leave (0 DMR), prune infected branches or to cut. Leave trees and prune trees were tagged with numbered aluminum tags. Trees to be cut were marked with tree paint.

In general trees with DMR of 3 or less were considered prunable. It was apparent, however, that this criterion would result in removal of too many trees. Subsequently trees with DMR of 4, that had no dwarf mistletoe visible in the upper one-third of the crown were also left for pruning. Bole infections were not considered in these judgments.

Of the 52 diseased trees, 31 were assessed as having too much infection for pruning; thus were removed from the stand. The remaining 21 were pruned. All treatments

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[1/] Hawksworth, Frank G. 1977. The 6-class dwarf mistletoe rating system. USDA Forest Serv. General Technical Report RM-48.

Table 1

Ponderosa Pine Dwarf Mistletoe Control Demonstration
Stand Characteristics

Location	Plot Size (acres)	Approximate Basal Area (sq.ft/acre)	Average DBH (inches)	Density Trees/ Acre	Actual Healthy	# Trees Infected	Average DMR	Cut # %	Pruned # %
Trail West Light	0.2	100	10.2	130	12	14	1.6	1- 4	13-50
Trail West Heavy	0.2	140	9.0	220	0	38	5.2	30-79	8-21
Stonewall	0.3	110	7.0	200	11	49	2.5	17-28	32-47
Air Force Academy	0.3	80	4.9	423	38	89	2.6	53-42	36-28
Genesee Mtn. Park (pine component)	0.4	120	8.2	212	19	67	3.3	41-49	25-29

All treatments were carried out immediately by the foresters that marked the area.

CASE 2

A similar demonstration plot was also established in 1971 at Stonewall in the south end of the Front Range (Las Animas County). The selected stand was pure ponderosa pine and was also part of a subdivision for summer homes. The characteristics of the selected plot are shown in table 1.

Of the 49 diseased or dead trees, 17 were removed (1 dead) and 32 were pruned. Criteria for these decisions were similar to those developed for Trail West. The only difference was that only trees of DMR of 3 or less were saved and pruned if necessary. As in the Trail West area, local residents disposed of all slash and debris after we had finished.

CASE 3

The United States Air Force Academy, south of Colorado Springs, has an extensive area of ponderosa pine, much of which is infected with *A. vaginatum*. The third pruning demonstration plot in 1971 was established, in cooperation with the Resident Forester, in a pure pine stand designated as "greenbelt" adjacent to the Staff residential area known as Douglas Village (table 1).

On this plot, as indicated by the lower average diameter and higher density of the stand, the decision to either cut or prune a tree was based on crown class, appearance (vigor), spacing and DMR. Consequently, some trees were cut in all of the infected DMR classes (i.e., 1-6). Of the 89 trees in question on the plot, 53 were cut (6 dead) and 36 were pruned. All trees were marked for either cutting or pruning by our crew and in this case, the subsequent work and clean up was done by the Academy's forestry crews.

CASE 4

The City of Denver owns extensive acreages, in many small parcels, of forested mountain lands west of the City, which are managed and developed as parks. Depending on degree of development and proximity to the City, these parks are extremely high-use areas. In common with most of the Front Range, ponderosa pine in these parks is moderately to heavily infected with dwarf mistletoe and in 1973 was imminently threatened by mountain pine beetle. The Colorado State Forest Service was then invited to install a dwarf mistletoe control demonstration in one of the Denver Mountain Parks. Genesee Park, approximately 10 miles west of the City, adjacent to Interstate 70, was selected and a 0.4 acre plot established next to the main picnic area. This stand was 85 percent ponderosa pine and 15 percent Douglas-fir (see table 2).

The plot was marked, cut and pruned by the local Colorado State Forest Service District crews after they had received training in dwarf mistletoe assessment and pruning techniques. Of the 67 infected or dead trees 42 were cut (1 dead) and 25 were pruned. Cut trees and larger branches were cut into firewood length. The smaller material was chipped on-site and distributed over the site. All work was done in July, during the peak of the day-use season. All firewood bolts from each day's work literally disappeared overnight which eliminated the disposal problem.

Table 2

Plot Summary -- After Treatment

Location	DMR	Total Trees	Number Dead	Number Cut	Number Pruned	Number Healthy	Total Remaining	Percent Residual
Trail West Light	1.6	26	0	1	13	12	25	96
Trail West Heavy	5.2	38	6	30	8	0	8	21
Stonewall	2.5	60	1	16	32	11	43	72
Air Force Academy	2.6	127	6	47	36	38	74	58
Genesee Mtn. Pk.	3.3	86	1	41	24	19	43	50

Table 2 summarizes the treatments that were applied to each plot.

Figure 1 illustrates the relationship between the original stand average DMR and the number of trees that are removed in this type of treatment. Basically, for every 0.1 rise in the stand DMR there is a rise of about 2 percent in the number of trees that should be removed. If we assume that the average property owner can tolerate removal of a maximum of 60 percent of the stand the breaking point is stand DMR of somewhat less than 4.0.

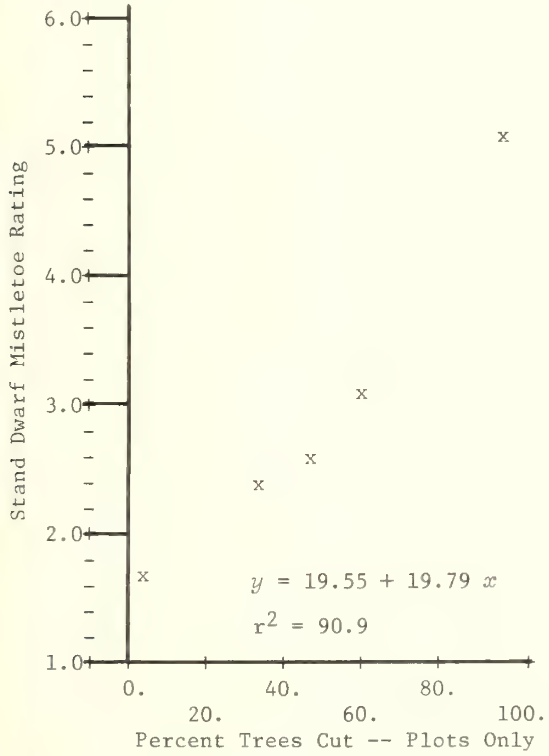

Figure 1--Relationship between stand dwarf mistletoe rating and tree removal.

The parallel between this and the tree DMR, i.e., 4.0 is the maximum for which pruning is feasible, is striking and provides more evidence of the validity of the 6-point rating system.

Table 3 shows the changes, on a per acre basis, of the total stand characteristics. Figures 2 and 3 show changes in basal area and density in relation to the average DMR.

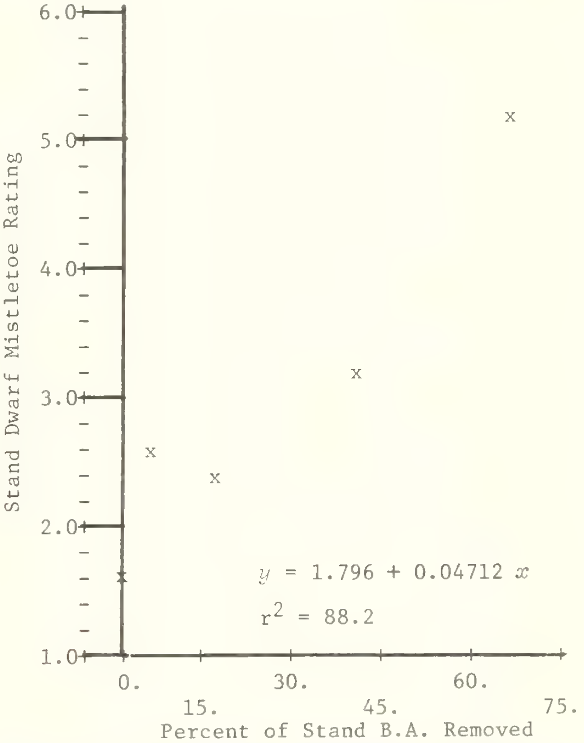

Figure 2--Relationship between stand dwarf mistletoe rating and percent of basal area removed.

All the previous cases dealt with ponderosa pine, infected by *Arceuthobium vaginatum* in forest-residential situations. The last case I will present was an experience with lodgepole pine -- *A. americanum* -- in an incorporated municipality.

Table 3

Plot	DMR	Approximate B.A.		Pct. of	T/A Density		Pct. of	Average DBH	
	Original	Orig.	Residual	Original	Orig.	Residual	Original	Orig.	Residual
Trail West Light	1.6	100	100	100	130	125	96	10.2	10.2
Trail West Heavy	5.2	140	45	34	220	35	16	9.0	13.0
Stonewall	2.5	110	90	82	200	147	74	8.4	8.5
Air Force Academy	2.6	80	75	94	423	247	58	4.9	5.5
Genesee Mtn. Pk.	3.3	120	70	58	212	112	53	8.2	8.8

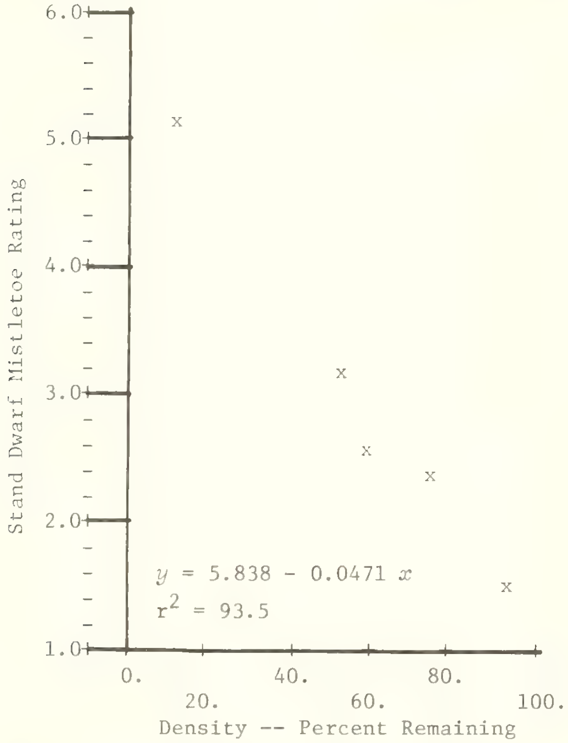

Figure 3--Relationship between stand dwarf mistletoe rating and trees per acre left after treatment.

CASE 5

The small City of Dillon has a permanent population of less than 500 and a transient population of approximately 3,000 during the summer and the skiing season. It is situated in the midst of the Rocky Mountains approximately 9,100 feet above sea level. It was established in the early 1960's on about 172 acres of lodgepole pine forest that was and still is heavily infested with dwarf mistletoe. The fathers of the town exhibited some foresight by designating a total of 30 acres, 17.5 percent of the total area, as green-belt or park area. In early 1974, the City Administration requested assistance and advice on managing the dwarf mistletoe infestations in these green-belts prior to developing them for recreation purposes. The Colorado State Forest Service evaluated the areas, wrote prescriptions and marked trees for either removal (severely diseased) or pruning (light or moderately diseased). Concurrently, the City retained a landscape architect to design picnic areas, nature trails and recreation sites in these green-belts.

A preliminary reconnaissance showed that as is usually the case, dwarf mistletoe was distributed throughout the area but varied considerably in intensity. Some patches of trees were in fact free of visible infections, some were completely feasible for pruning, some needed thinning and some should be clearcut.

A visit with the architect at this time revealed that his preliminary plan called for tree removal in some areas in order to place various structures, opening up other areas for easier use and placement of trails, playgrounds, tennis courts, picnic spots and parking areas.

Our first accomplishment was to convince the architect and the City Administration that the two plans, forest management and park development, should be made together with the dwarf mistletoe control prescriptions to lead. In fact, the winning argument was the discovery that the preliminary plan called for construction of a building in the spot presently occupied by the only mistletoe-free stand in the whole green-belt system. It was then agreed that we would make a detailed reconnaissance of the areas, make our various recommendations, and mark the trees that neede cutting or pruning. Then, the landscape architect would draw up his plans for the park

The 30-acre total is divided into 5 discrete units in the town site and around the lake shore that forms the south and east boundaries of the City. Within these 5 areas we distinguished 18 stands identifiable by the dwarf mistletoe incidence and treatments required.

Seven different treatments were proposed as shown below.

Recommended Treatment

1. Do nothing -- healthy stand
2. Sanitize -- remove dead and dying only and clean up slash and old debris
3. Remove infected overstory to protect abundant regeneration
4. Remove dead and heavy mistletoe (DMR 4+) and prune infected residual
5. Remove dead and dying, prune residuals and underplant
6. Prune infected trees
7. Clearcut

This plan, prescriptions and the landscape architect's subsequent plans were presented to the townspeople and Administration at a public meeting, following which the City agreed to initiate the program in key parts of the green-belt if we would follow up and train their Parks Department Personnel.

Two of the units (approximately 13 and 3.5 acres) were marked by us and two Dillon seasonal employees. All trees requiring either cutting or pruning were marked.

Decisions were again based on the 6-class rating system. Trees with DMR of 3 or less were pruned, Class 4 trees were judged individually and Class 5 and 6 trees were automatically cut. No data were recorded.

The actual treatments were conducted, throughout the next two summers, by the City Park Personnel.

SUMMARY

What has happened since? Public reaction in all 5 areas has been favorable. Initial fears of cutting trees, destruction of a "forest environment" and so forth were delayed.

Many of the principles and ideas developed here are incorporated in forest management plans written by Colorado State Forest Service field foresters for private forest lands. The City of Dillon, within the limits imposed by budgets, are interested in continuing and have asked us to mark additional units for 1978. Private landowners in Dillon, observing the improvement in pruned trees, have worked on their own trees. Denver Mountain Parks management have included dwarf mistletoe pruning-thinning in their management plans for several other Mountain Parks. The Air Force Academy includes control in their management plans. Other subdivisions and mountain municipalities have expressed interest in dwarf mistletoe control prescriptions.

What are the biological results? A re-tally of the 5 ponderosa pine plots this past winter yielded the data shown in table 4.

Table 4

Basal Area and Diameter Increments
Since Pruning

Location	Basal Area		Average DBH	
	1971	1978	1971	1978
Trail West Light	100	112	10.2	10.6
Trail West Heavy	45	48	13.0	13.8
Stonewall				
Air Force Academy	75	84	5.5	5.9
Genesee Mtn. Pk.	70	81	8.8	9.5

One intriguing observation within the 5 small ponderosa pine plots is that mountain pine beetle, while becoming or remaining at high levels in adjacent stands have not attacked the pruned trees within the plots. This effect is particularly evident at Genesee Mountain Park. The beetle, since the plot was established, has killed approximately 40 percent of adjacent trees. The mortality has occurred right up to the plot boundary. Only 1 tree within the plot was attacked the first year after treatment, but that attack was unsuccessful. No other attacks have been recorded through 5 beetle attack periods. The pruned plot at the Air Force Academy has also been free of mountain pine beetle while the surrounding stands have been infested each year.

To summarize, forest disease problems, and specifically dwarf mistletoe, are the same in a residential management situation as in a product management situation. Even the methods available to solve those problems are presently the same. Values are different! Tree owners, as opposed to forest owners, talk different economics. In the types of situations such as I have discussed here, if a control method is biologically feasible, economics seldom are a limiting factor in the application of that method.

Cures and preventive measures that may have occurred to the research community as they have worked on particular problems but were discarded because of forest product-based economics are now needed. If it will work, bring it to the residential forest owners. They will try it.

DWARF MISTLETOE CONTROLS IN BRITISH COLUMBIA[1]

G.A. Van Sickle and R.B. Smith[2]

Abstract: The distribution and impact are briefly reviewed for the four species of dwarf mistletoe in British Columbia, which mainly affect western hemlock, lodgepole pine, Douglas-fir and western larch. Control measures employed or tested by foresters in recent years, including aerial and ground surveys, stand thinning, residual removals, treatment of advance regeneration, fringe planting, scarification and selection cutting are described and discussed.

INTRODUCTION

British Columbia's forest area of 52.7 million hectares is 1¼ times the size of the state of California. Although managed under various land tenures, 95 percent of this forest is owned by the Province and forestry is the foremost industry, contributing 50 cents of every dollar of economic activity in the Province. The four species of dwarf mistletoe in British Columbia are mainly on western hemlock, lodgepole pine, Douglas-fir and western larch (Baranyay and Smith 1972). These tree species rank second, third and fourth in annual volumes harvested, and although larch is a minor species provincially, it is significant regionally, particularly in the southeastern corner of the Province.

In B.C., dwarf mistletoes occur over a great variety of vegetational zones which are influenced by a range in annual precipitation from as little as 30 cm up to 665 cm, by elevations from sea level to 1600 m, and by forest management systems ranging from a selective basis to clear cutting. Some comments on the distribution, major hosts, impact, surveys and control efforts for dwarf mistletoes in B.C. follow.

DISTRIBUTION, HOSTS AND IMPACT

Arceuthobium tsugense (Rosendahl) G.N. Jones

Two races of this species occur in British Columbia, one primarily on western hemlock (Tsuga heterophylla (Raf.) Sarg.), the other primarily on shore pine (Pinus contorta Dougl. ex Loud.). Both races are restricted to the forests west of the Coast Mountains.

Hemlock dwarf mistletoe occurs throughout coastal western hemlock forests from sea level to 1460 m. The most eastern extensions occur in major river valleys up to 180 km from saltwater. The principal host, western hemlock, is a climax tree species and one of the major species in the Coastal Western Hemlock Biogeoclimatic Zone (Krajina 1969). Stands with western hemlock dominating cover about 4 million ha, of which 15% are estimated to be infected with dwarf mistletoe. Current losses in stand volume growth in a 110-year-old stand were 4 - 5 m^3/ha/yr (Smith 1969). Extending these figures, annual growth losses in British Columbia are about 1.7 million m^3. Other damage includes bole swellings [12 percent of the merchantable volume of severely infected trees in one 110-year-old stand (Hunt 1971)], up to 30 percent larger knot size and increased bole taper (Smith 1969).

Within the Coastal Western Hemlock Zone, western hemlock is both a climax species and an important constituent of regeneration after logging and other disturbances. It also survives well as an understory tree, and small residuals and advanced regeneration often remain after logging.

Hemlock dwarf mistletoe also occurs in the Coastal Douglas-fir Zone but, in this drier zone, it is restricted to the edaphically wetter sites suited to hemlock. Clear cutting in this zone will reduce disease incidence because of the considerable regeneration of resistant species.

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[1] Paper presented at "A Symposium: Dwarf Mistletoe Control Through Forest Management", Berkeley, California, April 11-13, 1978.

[2] Research Scientists, Canadian Forestry Service, Pacific Forest Research Centre, 506 West Burnside Road, Victoria, British Columbia. V8Z 1M5. The willing cooperation of numerous industrial and B.C. Forest Service personnel in providing details of specific field trials was appreciated.

In B.C., only one record exists of hemlock dwarf mistletoe on mountain hemlock (Tsuga mertensiana (Bong.) Carr.), a strong contrast to northern California where mountain hemlock is the principal host.

Shore pine dwarf mistletoe severely damages some shore pine stands in south coastal B.C., particularly in the Coastal Douglas-fir Zone up to 725 m elevation. Shore pine is highly shade intolerant and forms nearly pure stands only where water deficits or excesses limit establishment of competing tree species.

With the relatively low commercial value of shore pine, growth impact studies have not been done. However, the intensification of mistletoe on shore pine is more rapid than on hemlock and equals that reported for lodgepole pine mistletoe (Wass 1976).

Arceuthobium americanum Nutt. ex Engelm.

Lodgepole pine dwarf mistletoe is the widest ranging mistletoe in B.C., infecting roughly 1.8 million ha. It is restricted largely to areas east of the Coast Mountains and south of Latitude 57°N, with a few extensions westward along major river valleys. The elevational range is 150 - 1600 m.

The most extensive infestations occur in the Aspen-Lodgepole pine-Douglas-fir Biogeoclimatic Zone in the south-central Interior. Here, lodgepole pine maintains a near-climax role as a result of the cold, dry climate and a high frequency of fire.

Lodgepole pine dwarf mistletoe also occurs in the Sub-boreal Spruce, Engelmann Spruce-Subalpine Fir and Interior Douglas-fir Zones, where lodgepole pine is essentially a pioneer species. A lack of extensive infestation in the Interior Western Hemlock Zone reflects the low frequency of fires and a highly varied composition of resistant regeneration species.

Growth impact data are available from several studies. From single-tree comparisons, estimated stand volumes in Alberta were reduced 18 to 32 percent by mistletoe infection (Baranyay and Safranyik 1970). Data of Dobie and Britneff (1975) indicate a 30 percent lower growth rate in infected than in healthy trees. Similar growth losses were found in surveys of the Cariboo District, which will later be discussed in more detail. Applying an average estimated growth loss of 1.4 m^3/ha/yr to the infected acreage, the annual loss in B.C. is about 2.5 million m^3.

Arceuthobium laricis (Piper) St. John

The principal host, western larch (Larix occidentalis Nutt.), is a particularly shade intolerant species restricted to southeastern British Columbia. Larch mistletoe occurs throughout most of the host range at elevations from 300 to 1460 m. It is present mainly in the Interior Western Hemlock Dry Subzone and the Interior Douglas-fir Wet Subzone.

Although the area affected is much less than that infected by hemlock and lodgepole pine mistletoes, impacts are locally very important. Increased mortality and drastic effects on merchantable yields found elsewhere [less than 20 percent of potential (On and Dooling 1969)] could be expected in British Columbia.

Arceuthobium douglasii Engelm.

Douglas-fir dwarf mistletoe has the smallest range of the B.C. mistletoes. It is confined to the extreme southern interior, primarily in the Okanagan Valley and along the south end of Kootenay Lake. It occurs almost exclusively on Douglas-fir at elevations from 300 to 1350 m in the wetter portion of the Ponderosa Pine Zone and in the Interior Douglas-fir Zone.

Damage is severe in individual trees and stands. Top killing is common. Reductions in merchantable volumes of 73 percent have been reported for western Montana (Haglund and Dooling 1972) and similar losses might be expected in B.C. Total growth impact is small compared to hemlock and lodgepole pine mistletoes, but forest management in these zones is often on a selective-cut basis, making control of Douglas-fir mistletoe a greater problem.

MISTLETOE SURVEYS

Dwarf mistletoes have been collected in B.C. since 1901, with more than 1500 records now present in the Canadian Forestry Service's Forest Insect and Disease Survey Herbarium in Victoria. A prism plot survey in 1969 in 121 areas of known mistletoe indicated the severity of infection in 80- to 200-year-old stands and provided for each species a graphical relationship between the proportion of host trees infected and the severity of infection (i.e., incidence vs. intensity).

The presence of dwarf mistletoe is one of the nine indicators used by the B.C. Forest Service Inventory Division to indicate a suspect tree in which some cull (non-merchantable portion owing to defect) may be expected. Each year several thousand inventory plots are established or revisited; however, as staff is largely seasonal, and only stem swellings are included, the results are of limited value. A resurvey of 16 areas by the Forest Insect and Disease Survey indicated a great diversity in the completion of pathological remarks and, on average, a 70 percent underestimate of the incidence of dwarf mistletoe. An assessment of growth loss or mortality owing to mistletoe is not yet included in the inventory system.

Roadside surveys for dwarf mistletoe have been employed in various states. In 1972 and 1973, the late J.A. Baranyay initiated a similar survey of lodgepole pine mistletoe in the Cariboo Forest District, an area with 6.9 million ha of forest land in B.C.'s central Interior. This district was selected because lodgepole pine comprises almost half the mature volume in the district and has the greatest concentration of lodgepole pine mistletoe. B.C. Forest Service 1:15840 scale forest-type maps were used to preselect accessible areas in which lodgepole pine was predominant. Of 1118 km travelled through lodgepole pine stands, 28 percent were judged healthy, and 41 percent lightly, 20 percent moderately and 11 percent severely infected. Additional ground sampling involving 473 one twenty fifth-hectare plots in 24 stands indicated that the roadside surveys may adequately classify the level of infection in a broad forest district, but they were only accurate about half the time for specific, individual stands. On average, moderately and severely infected trees were 2.7 to 3.7 m shorter, respectively, than healthy trees of similar diameters, and volumes per acre were reduced 25 to 35 percent.

Detection of dwarf mistletoe on aerial photographs was demonstrated for jack pine in Alberta (Muir and Robins 1973), but the smaller or less frequent brooms and the lower mortality and subsequent stand opening in lodgepole pine compared to jack pine may require modification for B.C. conditions. A study in lodgepole pine by Baranyay (1968), largely thwarted by technical and contract difficulties, suggested that oblique aerial photos were preferable to verticals; that at a 1:7920 scale, stand structure anomalies (openings, stocking or canopy) on color photos may indicate high disease intensity; and at a 1:2400 scale, individual, heavily infected trees preselected during ground surveys were distinguishable. In 1975, the B.C. Forest Service endeavored to determine the distribution and severity of lodgepole pine dwarf mistletoe in a management unit, using air calls, low level photography and ground surveys (Hanson 1975). Ground plots employing the six-class mistletoe rating system were almost immediately discounted as too time-consuming for the information obtained and because access was often restricted. Subjective observational records in stands and along roadsides were accepted as a first order estimate of the abundance of disease. The most promising survey method comes with the observation that an experienced classifier in a helicopter, and very familiar with conditions on the ground, could usually recognize and classify the mistletoe infection level of various type islands. An oblique view of large mistletoe brooms in the lower crown or in trees near stand openings was the basis for identification and the information was recorded directly onto aerial photographs, then transferred to forest-type maps. Brooming was not distinguishable in low level, vertical photography. Typing of 1:15840 scale photography directly for mistletoe infection was not possible, but the typical open, overmature pine stands produced by numerous light ground fires are visible and highly suspect for such stands in the central Interior are frequently infected with mistletoe.

SILVICULTURAL TREATMENTS IN YOUNG STANDS

Juvenile spacing has not been widely practised in B.C., totalling only slightly more than 1200 ha on crown Public Sustained Yield Units in 1976. However, several companies on the coast are now treating up to 1000 ha per year. The Provincial Forest Service contracts out the majority of its spacing, but incorporates specific requirements if mistletoe is recognized as a problem. According to the species of mistletoe present, susceptible species are identified and selected against, all medium to heavily infected trees must be cut and the spacing requirement is waived to accommodate this regulation, and in some areas a corridor around the infection is cut of all susceptible trees, regardless of size and condition.[3]

To date, spacing by forest companies has fortunately been mainly in non-susceptible or uninfected stands; however, a recent trial in a 9 ha severely infected young stand provided some indication of possible problems in coastal western hemlock stands. Spacing in 1976 reduced the stocking of this stand from 8350 to 950 stems per ha but, changed the mistletoe situation very little. Of the selected crop trees, 98 percent were infected, with an average infection rating of 2.1 compared to 83 percent and 2.5 for the cut trees. Based on a stump examination, 62 percent of the trees were residual from the logged stand, averaging 37 years compared to 20 years for the regeneration. At the time of logging, these advanced regeneration averaged 2.2 m in height. With a significant decrease in the acreages now being slash burned, mistletoe will be an increasingly important problem, necessitating greater emphasis on "clean" logging with a minimum of residuals left, and earlier spacing of infected stands before a high proportion of the trees are infected.

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[3] B.C.F.S. Reforestation Div. 1976. Contract specifications for juvenile spacings.

Only with time will we know if spacing of the above stand will greatly stimulate mistletoe intensification because of increased seed production and dispersal efficiency, or if host height growth will sufficiently exceed the upward spread of the disease to confine the mistletoe to the lower crown level. In 1976, on average, infections were contained within the lower 42 percent of the live crown length but, 1 year after treatment, 80 percent of the tagged, older and apparently dormant swellings had produced an average of 7.3 aerial shoots, and the number of shoots on active swellings had doubled.

Eradication and Thinning Trials in Lodgepole Pine as a Dwarf Mistletoe Control

In the central interior of B.C., vast but unquantified acreages of young, infected lodgepole pine exist. Silvicultural treatments have been considered as a means of preventing or reducing the loss in stand values from the progressive intensification of dwarf mistletoe, but precise information on the effectiveness of such sanitation procedures was lacking. In the event that management of such stands would some day be economic and more widely applied, the late J.A. Baranyay, in 1967, initiated a Canadian study to determine the effectiveness of two thinning methods to control dwarf mistletoe. The 23 fifth-hectare plots were re-examined in 1976-77 and the data are being summarized.

In the 9 years of the study, the average percentage of trees infected gradually increased from 45 to 68 percent (+ 23 percent) on the infected untreated plots, while decreasing from 42 to 37 percent (- 5 percent) with thinning and pruning treatments and from 52 to 18 percent (- 34 percent) when complete eradication was attempted. Comparable changes in average stand infection ratings were + 0.62, - 0.08 and - 0.64, respectively. However, despite the three treatments each plot received at 3-year intervals, mistletoe was not eradicated from any stand. Assuming an average increase in stand infection index, the eradication plots would reach the 3.0 level at which growth losses are felt to be significant in about 40 years, a 20 year gain over comparable untreated plots. Nonetheless, such trained-labor intensive treatments in immature lodgepole pine are unlikely to be common soon, and better returns would result from control measures done in conjunction with the harvesting of infected stands to establish vigorous, healthy regeneration.

Post Harvest Removal of Residuals to Control Dwarf Mistletoe

Several companies have undertaken residual removals in coastal western hemlock, usually as off season work for a small, permanent crew whose primary task is tree planting. Trees are usually felled or girdled to guarantee results and to avoid possible environmental or worker safety concerns from the use of herbicides. At least one company has attempted to "hack and squirt" the few severely infected residuals on more than 16 ha. Tordon 101 and Glowon (MSMA) were injected, but both trials were judged failures, with 5 percent of the trees killed, or only a few branches killed, respectively. Neither treatment had any apparent effect on the aerial shoots of the mistletoe until the host branch or tree died. Axe or saw girdling was very effective if done below the lowest live branch, but trees treated in July 1975 retained sufficient vigor that mistletoe seeds were discharged normally in September. To prevent seed dispersal, trees had to be girdled early in April before flush.

TREATMENTS BEFORE, DURING AND AFTER STAND HARVEST

Residual falling

With the current level of forest management in B.C. and considering dwarf mistletoes' symptoms, host specificity, and its nature and slow rate of spread, this disease can best and most economically be controlled during the logging and stand re-establishment stage. Specifically, this involves cut block layout, adherence to a residual falling rule, and elimination of infected advance regeneration, particularly in the coastal hemlock and interior lodgepole pine zones. Old-growth harvesting still dominates B.C. forestry but, in some cases, special early harvesting of severely infected coastal hemlock stands before rotation age has been allowed with the objective of quickly returning high site land to its full productive potential. There is, however, no firm Provincial policy for assessing stand productivity or silvicultural programs, and much depends on the personal convictions, influence and initiative of local forestry officers and industrial personnel.

A condition of harvest, applied and sometimes enforced by the B.C. Forest Service, may require the operator in a clear-cut area to remove or destroy all trees over 3 m in height. The purpose may be either aesthetic, fuel hazard abatement, or for silvicultural purposes primarily to control the spread of dwarf mistletoe. Slash disposal to reduce fire hazard can also effectively reduce the potential mistletoe problem; however, burning is not always environmentally and locally accepted and acreages treated have declined in recent years. Also, spot and landing burns have been favored more than broadcast burning, leaving, in some cases, living infected residuals which should be cut. In the absence of critical cost-benefit analysis covering the wide range of site and disease levels encountered, some forest companies, particularly on the Coast, are questioning the universal application of the residual falling clause. In such cases, an evaluation of the mistletoe in the stand before logging is an important, but often ignored consideration which may allow guidelines to be more site specific, with the greatest efforts directed toward the relatively pure hemlock stands. Alternatively, some companies attempt to alter the forest stand composition by planting non-susceptible species, usually Douglas-fir, provided the site is acceptable.

Control Efforts in Lodgepole Pine

In 1976, 85 percent of the stand improvement work for mistletoe control in the Province was in the Interior lodgepole pine region of the Cariboo Forest District. Control efforts were scattered and token until 1974, but since then the area treated each year has gradually increased, the licensee undertaking a greater proportion of the work each year. In 1977, of the 2270 ha treated for mistletoe, 230 ha were drag scarified, residual falling was conducted on 40 ha, and advanced regeneration was eradicated by hand on 2000 ha; 77% by the licensee, 23% by the Provincial Forest Service. Even so, with 6800 ha of infected lodgepole pine harvested in this District each year, control efforts are still minimal and ad hoc. No method of priorizing stands for treatment i applied, nor is the presence of mistletoe systematically classified and recorded.

Control measures employed and tested in recent years are mainly before, during and after harvest of infected mature stands. When a cut application is received and mistletoe is recognized as a problem, future control costs can be minimized by careful planning of the cut block boundaries. Non-susceptible or uninfested stands, water, rights-of-way, etc., are used to minimize the length of infected margin created, and cut block size is usually regular and maximized around 80 ha to provide the greatest area with the least perimeter. Where unacceptably large clearcuts would result from expanding cutting boundaries to the infection limits, a high priority is placed on the adjacent fringes for cutting at a later date, usually once the regenerated stand provides adequate game cover With current logging by tractor-mounted shears or feller-bunchers to a 15 cm diameter stump-height limit, only skinny poles and advance regeneration remain. With some instruction and guidance, machine operators can make several passes through susceptible patches while leaving any existing non-host species undamaged.

Post logging mistletoe control has mainly involved eradication of advance regeneration, using hand shears. Since 1974, more than 4850 ha have been treated at an average cost of $20 per hectare. Drag scarification with chains or shark finned barrels and chains has been used on more than 250 ha to eradicate dense stocking of advance regeneration. Although initially many wounded saplings sprung back up behind the drag, very few residual stems remained 2 years after treatment. However, these sites were highly exposed and recent summers have been hot and dry; hence, there remains a concern that dragging may not kill saplings as effectively in wetter sites or years. Some combinations of partial scarification and hand eradication have been used in attempts to also control stocking. Average treatment costs were $54/ha, comparable to $62/ha in the Prince George District further north.

Fringe planting a 36-m wide strip adjacent to infected borders with resistant species such as Douglas-fir or spruce totals about 47 km, equivalent to 170 ha. The treatment may reduce the spread of mistletoe but does not prevent it, owing to the rapid natural regeneration and competition by lodgepole pine. Since periodic eradication of the pine would be additionally expensive, the planted stock are often off-site with poor survival, and initial planting costs are high ($270/ha), fringe planting is not likely to be more widely applied.

In 1976, in conjunction with a mechanical thinning trial, 8 ha of infected immature edge were removed, partly by hydro axe and partly by windrowing with a small dozer and then burning. An average cost for the trial was $370/ha. Such treatments may be more economical and widely practised when adjacent stands are logged as a means of removing the, by then, young infected stands adjacent to heavily infected mature borders.

An estimate is not available of the acreage of young second-growth pine on which dwarf mistletoe is a problem but, with about 6800 ha logged each year, the backlog is substantial. In areas felled by hand or without enforcement of residual falling, individual trees and patches of infected residuals often remain. Falling of the residuals is being done as time and money permits. To date, 170 ha have been treated, but costs are highly variable ($37-300/ha), depending on the density, distribution and size of the residual trees.

Selection Cutting of Infected Douglas-fir in the Okanagan Valley

Douglas-fir mistletoe is scattered but common in the Okanagan and Kootenay valleys and, as indicated by one 1975 Tree Farm Licence inventory, about 25% of the timber may be infected. As early as 1965, the Forest Service sanitized a 4.7 ha previously logged area as a pilot control project. Visibly infected trees were piled and burned, small trees with single branches infected were pruned, and a road and 15 m isolation strip surrounded the plot. Additional infections throughout the plot were removed in 1971, but it became apparent that complete eradication was not feasible and a reduction of the mistletoe to a reasonable level is all that can be expected.

Since 1969, one forest company has logged or relogged 727 ha and removed infected residuals on an additional 1000 ha in an attempt to control dwarf mistletoe. Efforts have been complex because Douglas-fir, lodgepole pine and larch mistletoes all occur in varying proportions in parts of the area (ponderosa pine is the only common resistant commercial species) and yet overstory shade is critical for successful regeneration in these very dry sites. Treatments in merchantable stands have included diameter limit cutting with felling of infected residuals, some scarification, piling and burning of slash, leaving non-host seed trees, trial plantings to change the species composition, and two or three pass strip logging. Areas of non-commercial volume, still unidentified and unmeasured, will require a special program of rehabilitation before they again support a productive forest.

DWARF MISTLETOE MANAGEMENT AIDS REQUIRED OR UNDER DEVELOPMENT

Current efforts in dwarf mistletoe research at the Pacific Forest Research Centre are mostly directed to the development of a mathematical model of hemlock mistletoe spread, based on the data collected since 1964 on seed dispersal, interception, infection and rates of intensification. The model will generate values of the infection level and pattern in regeneration at varying densities and distances from infected residuals to assist forest managers in determining the timing, degree and cost of sanitation spacing treatments. Surveys and advice will continue to be provided to foster an awareness and practice of all reasonable management alternatives aimed at reducing current and future losses from dwarf mistletoe.

Numerous people, companies and forest service groups scattered throughout B.C. are expending considerable effort toward the control of dwarf mistletoes through forest management. Much, however, is ad hoc, relying largely on an individual's conviction, persuasiveness and perhaps stubbornness to initiate and complete any treatments. Major requirements for improved management include several inter-related factors:

i. a Provincial policy and funding for silvicultural programs aimed at pest management.

ii. quantified, long-term forestry data to identify and assess losses and provide the basis of assigning specific control actions according to economic or forest site values.

iii. monitoring of current control projects to obtain a biological and economic assessment of present control practices. Currently most effort is expended solely in the hope of having mistletoe-free or acceptable second-growth stands.

LITERATURE CITED

Baranyay, J.A.
1968. Experiment with aerial colour photography for detecting dwarf mistletoe infected lodgepole pine stands in the Alberta-Territories region. Can. Dep. For. Internal Rep. A-12. Calgary, Alberta. 35 p.

Baranyay, J.A. and L. Safranyik
1970. Effect of dwarf mistletoe on growth and mortality of lodgepole pine in Alberta. Can. Dep. Fish. and For., For. Serv. Publ. 1285.

Baranyay, J.A. and R.B. Smith
1972. Dwarf mistletoes in British Columbia and recommendations for their control. Can. For. Serv. BC-X-72, p. 18. Victoria, B.C.

Dobie, J. and A.A. Britneff
1975. Lumber grades and volumes from lodgepole pine infected with dwarf mistletoe. Wood and Fiber 7(2): 104-109.

Haglund, S.A. and O.J. Dooling
1972. Observations on the impact of dwarf mistletoe on Douglas-fir in western Montana. USDA, For. Serv., Northern Region, Rep. D-72-1.

Hanson, G.F.
1975. Lodgepole pine dwarf mistletoe survey -- Westlake public sustained yield unit. BCFS, special project. Mimeo. report. Victoria, B.C.

Hunt, K.
1971. A comparison of kraft pulping of sound and dwarf mistletoe-infected western hemlock wood. Can. Dep. Fish. and For., For. Serv., Inform. Rep. VP-X-78. Vancouver, B.C.

Krajina, V.J.
1969. Ecology of forest trees in British Columbia. Ecology of West. North Amer. 2(1): 1-147.

Muir, J.A. and J.K. Robins
1973. Detection of dwarf mistletoe of jack pine on aerial photographs. Plant Dis. Reptr. 57: 951-954.

On, D. and O. Dooling
1969. A study of the effect of dwarf mistletoe infection on the growth of western larch. USDA, For. Serv., Div. State and Private For., Missoula, Mont. Misc. Rep.

Smith, R.B.
1969. Assessing dwarf mistletoe on western hemlock. For. Sci. 15(3): 277-285.

Wass, E.F.
1976. Ecology of shore pine stands infested with dwarf mistletoe on southeastern Vancouver Island. Can. For. Serv., Rep. BC-X-142.

EVALUATION AND SUCCESS OF DWARF MISTLETOE CONTROL IN CALIFORNIA'S EAST-SIDE JEFFREY PINE TYPE[1]

Philip H. Intorf[2]

Abstract: The first and most intensive attempts at dwarf mistletoe control on the Plumas National Forest were made in the Milford Ranger District on the east side of the Sierra Nevada. These control attempts were possibly the most extensive in the Forest Service's California Region. Survey and control procedures were based on the limited knowledge of dwarf mistletoe available at the time. Experience and success were achieved largely by trial and error as knowledge in control of dwarf mistletoe was gained. Many hundreds and thousands of acres of formerly heavily infected, deteriorating, and dying stands of Jeffrey pine are now producing acceptable increments of growth. More knowledge needs to be gained in determining just what degree of dwarf mistletoe control is necessary to produce acceptable growth gains and still not allow this plant pest to seriously damage the ultimate regeneration of the Jeffrey pine stands.

INTRODUCTION

Some dwarf mistletoe control was attempted on the east side of the Plumas National Forest on the Milford Ranger District as early as 1955 and 1956. Post-sale silvicultural work at that time consisted almost entirely of quality pruning of trees selected as the potential crop trees. No pre-commercial thinning was done in connection with the quality pruning at the time.

The work aimed at controlling dwarf mistletoe consisted primarily of supplemental pruning of dwarf mistletoe-infected branches on the quality pruned trees. In addition, the most severely infected trees in very heavily infected stands of small regeneration only were cut. A complete pre-commercial thinning was not attempted, because this was not then an accepted region-wide post-sale silvicultural treatment. It soon became apparent that occasional pruning and individual tree cutting was not too effective because relatively little control work was being done and because large amounts of dwarf mistletoe infection remained in some trees not being treated. Also, many large infected over-story trees had not been removed in the timber sales preceding the post-sale silvicultural work.

In 1958, the California Regional Office personnel--particularly specialists in insect and disease control--became interested in the dwarf mistletoe problem because of the reports by the District Ranger, Leonard Beltz, that severe dwarf mistletoe infection was being found in reproduction and pole size stands. He estimated that about 10,000 acres were heavily infected with dwarf mistletoe and that some degree of infection occurred on over 25,000 additional acres.

A Plumas check scaler, Herb Hard, who had previously worked on the Milford District as the Timber Sale Officer reported that some of the heavily infected stands were in areas that did not have much infection at the time he was scaling and marking timber on the District. Thus, the District was concerned that the intensity of dwarf mistletoe was increasing tremendously in the stands that had been opened up by the first timber cutting.

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[1] Presented at the Symposium on Dwarf Mistletoe Control Through Forest Management, Berkeley, Calif., April 11-13, 1978.

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FIRST DWARF MISTLETOE SURVEYS

The Regional Office personnel who became interested in the dwarf mistletoe problem at the time were Tom Harris, Reed Miller, Roy Blomstrom, and Neil MacGregor. The first approach to the problem was to make an intensive dwarf mistletoe survey before a timber sale in some areas of intense dwarf mistletoe infection. Infected trees in the area were to be sampled, and the area was to be mapped as having heavy, medium (or light), or no infections. In the timber sale preparation, all overstory trees of merchantable size, and infected with dwarf mistletoe were to be marked for removal in the subsequent timber sale. Post-sale silvicultural work in infected stands of regeneration was to consist of removal of trees with bole infections and of trees heavily infected with dwarf mistletoe. Limb infections were to be pruned from all leave trees.

Pre-commercial thinning of young stands was just starting in the California Region at this time. It was decided not to thin, however, because just how much latent infection would show up in the leave trees was not known.

The first area chosen for an intensive dwarf mistletoe survey and a trial dwarf mistletoe control project was Snow Lake because the area was planned for timber sale and because the stands were heavily infested with dwarf mistletoe. The predominant species there was Jeffrey pine, but some ponderosa pine, white fir and incense cedar were present. Elevation averaged about 6,000 feet, and the soils were mostly of granitic origin. The sites were low, mostly III and IV, and rainfall averaged 20 inches or less annually. The area had been logged 18 years earlier and had been marked on a high risk basis. The cut averaged about 65 percent of the original volume so that dwarf mistletoe could have intensified appreciably in the 18 intervening years. All in all the area looked ideal for a pilot dwarf mistletoe survey and control project.

SAMPLING METHOD

The study approach was to survey the area and record all dwarf mistletoe infected trees on the sampled areas before any timber sale cutting took place. The area was sampled by a continuous strip survey, with strips ½ chain wide and 10 chains apart resulting in a 5 percent sample.

All trees on the strips were inspected and recorded as reproduction, poles, or merchantable trees more than 13 inches dbh. Nonmerchantable trees were recorded as uninfected or infected. For merchantable trees, infection was reported as none, light, medium, or heavy and all infected trees were to be cut. For reproduction and poles, all infected trees were tallied by 3 inch dbh classes judged as to whether they could be pruned or were to be cut because of infection too severe to prune. Infection was recorded by size class so that the cost of pruning and cutting trees could be estimated. No extensive thinning had previously been done, so costs of treatment had to be determined before control was to be attempted. Data were segregated and summarized by 5-chain transects, and a map of dwarf mistletoe intensity was prepared. Site was also systematically recorded.

From the survey data, a map was prepared showing stand infection rating based on the percentage of trees infected (1,600 acres sampled):

Infection	Percent	Acres
Little or none	0-3	70
Light	3-15	454
Medium	15-33	49
Heavy	over 33	1027
Total		1600

This pattern of intensity ultimately seemed to follow on most subsequent surveys, with the bulk of the acreage in the heavy and light infection categories and small acreages in the medium and noninfection categories.

RECOMMENDATIONS

The original recommendations called for: (1) Marking and removal by timber sale of all infected trees more than 16 inches dbh; (2) treatment for dwarf mistletoe control of all areas with little, light, or medium infection; and (3) no treatment of areas of heavy infection This recommendation was later changed to have all remaining trees and slash in heavily infected areas of site IV and better, bulldozed into windrows, burned, and the entire area replanted with Jeffrey pine seedlings. What actually happened on the Snow Lake trial area was this: (1) The timber sale area was marked and advertised but there were no bidders for the sale. (2) Additional uninfected timber area adjacent to the Snow Lake sale was added to the sale area to make it more attractive for bidders. The area was re-advertised, and sold about 2 years later. In the meantime in the intervening delay, about one-third of the trees marked in the original Snow Lake sale died--undoubtedly because of the combination of (a) the very heavy dwarf mistletoe infection, (b) the severe drought conditions during the period of 1958 to 1961, and (c) Ips and Dendroctonus insect attacks. (3) Much of the heavily infected area was clearcut, and the remaining heavily infected reproduction, poles, and slash were bulldozed into windrows and burned. The area was then replanted with Jeffrey pine seedlings. (4) Areas of light and medium infection were thinned lightly by removing the heaviest infected reproduction and poles. Mistletoe infested branches were then pruned from the remaining potential crop trees. After about 3 years, the area was reworked by completing the thinning by removing trees that showed up with bole infections or additional heavy branch infections. The remaining crop trees were inspected for new infections and pruned. After another 5 years the areas were reworked again by pruning additional dwarf mistletoe infections.

LATER DWARF MISTLETOE SURVEYS

In all subsequent timber sales, a dwarf mistletoe survey preceded all timber sale layout and timber marking. At first the very intensive surveys, as described, were used but later changed to more extensive surveys to delineate the areas of dwarf mistletoe infection intensity only. Finally, the separate dwarf mistletoe surveys were discontinued, and presence or absence of dwarf mistletoe and its intensity were mapped along with the timber sale layouts.

In the early stages of dwarf mistletoe control on the Milford District, it was not known just what results would come about. Precommercial thinning was new to disease control, pruning procedures were new, and certainly the results to be obtained were unknown. One definite requirement at the time was that, if dwarf mistletoe control was to be attempted in any area, it must be conducted as a 100 percent eradication or not attempted at all. All infested trees had to be cut or pruned free of mistletoe. This requirement resulted in the necessity for very difficult and expensive high branch pruning or removal of trees with branch infections too high to prune. Buffer strips were cut around areas where it was decided that 100 percent control could not be achieved; it was to be an "all-or-none" operation.

As more experience was gained and more knowledge became available in dwarf mistletoe behavior, the dwarf mistletoe control and precommercial thinning procedures were continually being modified. In the first control operations it was not known how much latent or new infections and bole infections would show up in the selected potential crop trees. And so excess numbers of potential crop trees were left and pruned at considerable additional cost. Also, as was the standard procedure in all early precommercial thinning, all stands were pre-marked before work commenced. Some of the changes which evolved were: (1) Two stage thinning--first, all obvious heavily-infected trees were cut out to open up the stands, and allowing for a better selection of uninfected or lightly infected crop trees before the remaining stand was marked. (2) Crop tree selection by force account crews, followed by pruning of crop trees (instead of pre-marking). (3) Contracting for thinning of pre-marked stands followed by pruning of crop trees by force account crews. Pruning by contractors did not result in acceptable removal of limb infections. (4) Contract thinning by cutter selection of crop trees followed by pruning by force account crews.

Over the years it became obvious that 100 percent control or complete eradication of dwarf mistletoe is a practical impossibility. Therefore, the "all-or-no control" requirement was relaxed. The questions then became: How much infection should be removed from a tree or stand? How much infection can be tolerated without an appreciable reduction in growth rate?

CURRENT STUDIES

At present studies are being conducted on the Milford District by the Pacific Southwest Forest and Range Experiment Station and the University of California by Dr. Robert F. Scharpf and Dr. J. R. Parmeter to determine what growth response has been achieved in the stands that had various combinations of pruning and thinning to control dwarf mistletoe. The studies are being made in stands that were (a) heavily infected and not treated, (b) heavily infected and thinned only, (c) stands with varying levels of infection that were thinned and pruned once, and (d) stands with several levels of infection that were thinned and pruned more than once.

The results should have a tremendous value in determing how much money, if any, should be spent in the future in reducing the intensity of infection on crop (leave) trees after thinning or pruning. The results may show that for the past 15 years of dwarf mistletoe control the increase in growth rate of treated stands is due largely to the effects of thinning and little to pruning.

SUMMARY AND CONCLUSIONS

Several factors might be considered with regard to the past control efforts. The intense control efforts, including heavy pruning, were followed because early prescriptions for dwarf mistletoe control work required 100 percent effort at control and not partial attempts. Results of these past efforts are now enabling us to study this approach, because new approaches are not possible without results of past trials as a foundation. The treatment of thousands of acres of infected stands during the past 15 years--even if done so to an unnecessarily intense degree--has resulted in vigorously growing healthy stands that undoubtedly would have been decimated by drought disease and insects in the meantime had they not been treated. During the past 2 years of extreme drought, none of these treated stands have been observed to have been hit by the drought or insects, while some other adjacent stands have been.

A study of results of the past 10 to 15 years may not be a long enough period on which to base future prescriptions. Perhaps over the years of an entire rotation some degree of dwarf mistletoe pruning may be necessary to prevent disease intensification that could ultimately cause unacceptable growth reduction. Some sort of shelterwood or partial cutting prescription may be necessary in many stands to ensure economical establishment of regeneration. And over the years of a rotation the buildup of dwarf mistletoe in the unpruned stand could result in severely infected regeneration if shelterwood prescriptions are to be depended on for regeneration establishment.

In the areas of very intense infection where all merchantable trees were cut and residual infected trees bulldozed and burned and the area replanted, successful regeneration could not always be achieved or could not be achieved economically because of several low-site factors. Rainfall averages 20 inches or less annually. Thus, soil moisture is not always adequate in the spring to assure seedling survival. Moisture holding capacity of loose granitic soils is low. Browsing of seedlings by cattle and deer is common. Some areas experience excessive damage by gophers. And competition for moisture by annual and perennial grasses, herbs, and brush is a problem. Replanting of some areas may be impossible without spraying grass and brush with herbicides before replanting. But the present restrictions on herbicide application makes this approach somewhat dubious for the future.

Thus, control of dwarf mistletoe through artificial regeneration of eastside Jeffrey pine stands is of limited value until problems of establishing successful plantations can be resolved.

CONTROL OF DWARF MISTLETOE ON TRUE FIRS IN THE WEST[1]

Robert F. Scharpf[2]

Abstract: The dwarf mistletoe *Arceuthobium abietinum* is a serious parasite of true firs (*Abies* spp.) growing on the Pacific Coast. Damage is most severe in old-growth and unmanaged fir stands. With information now available, the forest manager can develop management guides for control of dwarf mistletoe. Such information includes parasite-host specificity, size at which young trees become infected, growth rate of trees in relation to dwarf mistletoe buildup and spread, and effects of dwarf mistletoe on tree growth rate and mortality.

INTRODUCTION

The true firs (*Abies* spp.) are among the more important commercial softwood timber species in the Western United States. They are not only widely utilized in the United States but also are a valuable commodity in foreign timber markets. Unfortunately, fir stands in the West are often severely infested with dwarf mistletoe. This problem is caused almost entirely by a single species of dwarf mistletoe--*Arceuthobium abietinum*.

The firs are abundant in the West--particularly along the Pacific Coast. In California, for example, two fir species--white fir (*Abies concolor*), and red fir (*A. magnifica*)--make up about a third of the State's net cubic foot volume--or about 15 billion cubic feet out of the estimated total net volume of 51 billion cubic feet of commercial softwood. The Western States combined contain a net volume of about 45 billion cubic feet of true fir growing stock (Anonymous 1972).

Dwarf mistletoe is common on true firs--particularly in California and Oregon. Forest disease surveys conducted by the U.S. Forest Service in California in the 1950's and 1960's show that true firs are among the most heavily infested commercial conifer species in the State. About 40 percent of the red fir and about 30 percent of the white fir stands were found to be severely infested by dwarf mistletoes (California Forest Pest Control Action Council 1961). Thus, literally thousands of acres of pure fir and mixed conifer stands containing fir species are infested with this parasite.

The losses of timber attributed to this parasite in fir stands are not precisely known but are estimated to be enormous. For instance, old-growth firs, in particular, suffer severe losses. Reduction in growth and vigor from heavy infection, broken trees resulting from decay entering trunk infections, and mortality caused by insects attacking weakened trees account for much of the losses. Infected trees are also more subject to mortality from other factors, such as root decay fungi and moisture stress brought about by drought conditions. The losses attributed to dwarf mistletoe are not limited to timber values alone but also affect recreational and water shed values as well. Losses caused by dwarf mistletoes either directly or indirectly will probably continue at severe levels unless many fir stands in the West are brought under intensive management including dwarf mistletoe control as an integral part of the management plan.

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[1] Presented at the Symposium on Dwarf Mistletoe Control Through Forest Managment, Berkeley, Calif., April 11-13, 1978.

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PAST CONTROL EFFORTS

Within the last decade or two, control of dwarf mistletoe in true firs has been attempted almost entirely by harvesting old-growth stands. Fir stands, particularly pure stands, were harvested primarily by clearcutting, often in large blocks. Unfortunately, firs do not naturally reseed large clearcut areas well, and reliable fir planting stock has not always been available for regenerating fir sites. Also, other species selected for planting have not developed well on pure fir sites--Jeffrey pines in California, for example.

Clearcutting controlled dwarf mistletoe in many areas, but it has often created more problems than it cured. Today, where clearcutting is used, the trend is toward cutting smaller blocks or narrow strips in order to obtain natural regeneration of fir from adjacent stands. As good fir planting stock becomes available, many clearcut areas will no doubt also be planted. Although dwarf mistletoe has been controlled in the past by clearcutting in many pure fir stands, clearcutting today--particularly over large areas--is highly controversial--and many clearcuttings cause management problems more serious than dwarf mistletoe infestation. Therefore clearcutting should not be considered the only solution to dwarf mistletoe control in infested fir stands in the West.

With some exceptions, control of dwarf mistletoe in mixed conifer stands with fir, was almost entirely overlooked or disregarded before about 1960. In fact, because of early logging practices, the infestation by dwarf mistletoe in these mixed species stands has probably gotten worse. For example, until fairly recently in the West, firs were considered less desirable than other conifer species and commanded a relatively low market value. Thus, the higher value species, such as pines and Douglas-fir, were often selectively logged, leaving the infected true fir component of the stand behind. These residual firs often seeded into openings after logging. This practice of selective logging increased the proportion of firs in many stands. Dwarf mistletoe was able to readily spread from infested overstory to understory fir trees--particularly in the absence of pines and other nonsusceptible tree species that act as barriers to spread of seeds of the parasite. Thus, I feel certain that past logging practices in many mixed conifer stands has aggravated rather than alleviated the dwarf mistletoe problem in true firs.

PRESENT APPROACHES TO CONTROL

Enough information is now available to forest managers to allow them to develop guidelines for control. As more information becomes available from research, management guidelines can be improved and refined. A variety of factors bear on the development of guidelines for control.

The Parasite is Host Specific

It has long been known that the dwarf mistletoe on true firs is very host specific (Parmeter and Scharpf 1963, Hawksworth and Wiens 1972). One of the problems that confused foresters in the past is that occasionally more than one species of fir was found to be infected in some stands. Subsequent studies have shown that for the most part, only one dwarf mistletoe species infects firs, but it is made up of two indistinguishable plant forms that infect different fir species. These forms cannot be separated on the basis of outward physical characteristics, but they can be separated on the basis of the fir species they infect (table 1).

Table 1--*The species of dwarf mistletoe that infect true firs*

MISTLETOE	HOSTS
WHITE FIR DWARF MISTLETOE (ARCEUTHOBIUM ABIETINUM F. SP. CONCOLORIS)	WHITE FIR, GRAND FIR *PACIFIC SILVER FIR
RED FIR DWARF MISTLETOE (A. ABIETINUM F. SP. MAGNIFICAE)	RED FIR, NOBLE FIR
HEMLOCK DWARF MISTLETOE (A. TUSGENSE)	*PACIFIC SILVER FIR *NOBLE FIR

* occasional hosts

The white fir dwarf mistletoe is parasitic on white firs and grand firs, whereas red fir and noble fir are the principal hosts of the red fir dwarf mistletoe. Thus, in California, for example, the dwarf mistletoe that infects white fir will not infect red fir and vice versa. Also, seldom do both forms of the mistletoe occur on firs where the range of two or more fir species overlap. One additional factor that made the fir-mistletoe situation even more confusing is that firs growing in mixture with hemlock often become infected with hemlock mistletoe. But this situation is relatively uncommon in the West, and hemlock mistletoe is not considered a major concern in the management of fir stands.

Knowledge of the host specificity of dwarf mistletoes is of use in planning harvest cuts, thinning, and regenerating fir stands. The use of host specificity is probably the only method of silviculturally managing for dwarf mistletoe control that can be used for both even-aged and uneven-aged stand situations. The following examples of information useful for dwarf mistletoe control apply only to even-aged stand management.

Small Firs are Seldom Infected in Infested Stands

Studies have shown that red firs less than 3 feet in height are seldom infected by dwarf mistletoe, even in the presence of abundant overstory mistletoe (fig. 1) (Scharpf 1969). Infection rates increase dramatically in trees taller than 3 feet, however. Similarly, intensity of infection on small trees was low, but increased with tree size (fig. 2). Being able to regenerate an area either naturally or artificially until seedlings are 3 feet tall without fear of appreciable infection from dwarf mistletoe gives the manager a practical working tool for stand regeneration. Most plantation trees and natural regeneration that are 2 to 3 feet tall are considered well established, and infected overstory or residual trees that were left as a seed source or for shade should at this point be cut or harvested to avoid infection of regeneration. This knowledge of the relationship of seedling height to infection from surrounding overstory is particularly useful where infested fir stands are to be regenerated naturally by narrow strip clearcut, seedtree, or shelterwood methods.

Infected Firs Free From Overstory Infection and Growing Well in Height will Outgrow the Spread and Buildup of Dwarf Mistletoe

Results of long-term dwarf mistletoe studies Dr. J. R. Parmeter and I have made, provide information about the biology, spread, and buildup of dwarf mistletoe in young fir stands that is important in developing guidelines for control (Scharpf and Parmeter 1967, Scharpf and Parmeter 1976). We have found, for example, that the spread and buildup of dwarf mistletoe in young red and white firs is

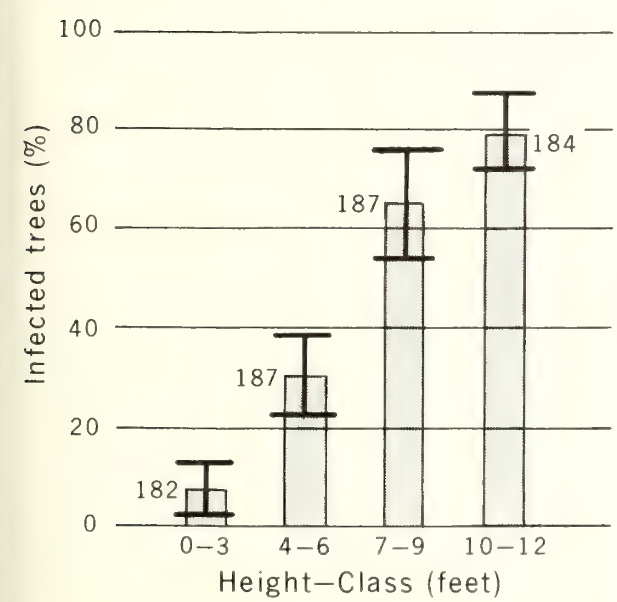

Figure 1--*Percentage of red fir infected in each height-class, with 95 percent confidence intervals.* (Scharpf 1969)

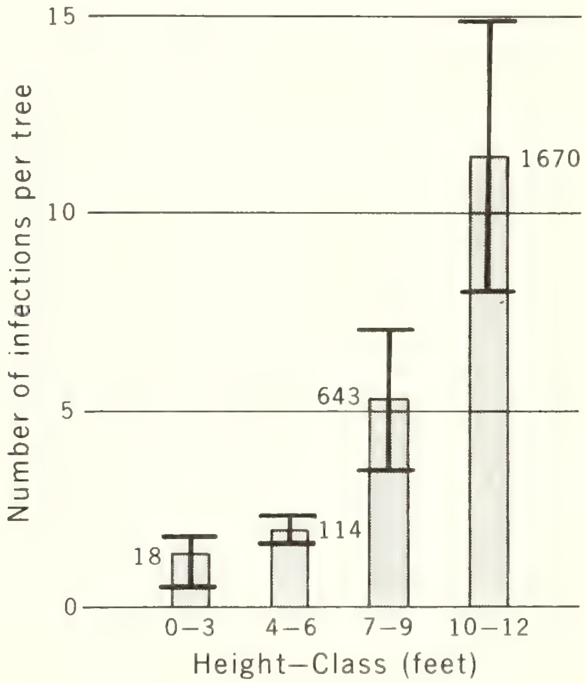

Figure 2--*Number of infections per infected tree in each height-class, with 95 percent confidence intervals.* (Scharpf 1969) inherently quite slow. Also, certain factors keep population levels low and help check the spread of the parasite. An important factor that influences spread and buildup is that the generation time of a mistletoe plant from seed production to infection and development of a new seed bearing plant is 5 years or longer. Furthermore, female dwarf mistletoe plants do not regularly produce fruit every year; often abundant fruit is produced only about once every 3 years. In addition, the percentage of the total number of seeds dispersed that cause infection is quite low. For instance, not all seeds land on susceptible branches but of those that do, we have found that usually less than 5 percent of them cause infection. Thus, the long generation time, sporadic seed production, and low infection rates result in a slow rate of buildup and spread of the parasite.

The physical characteristics or growth form of firs also limits spread of the parasite. The dense persistent foliage of true firs limits both the upward as well as the lateral spread of the parasite. For example, results from our long-term studies show that average distance of vertical spread of dwarf mistletoe in red firs and white firs is about 3 inches or less a year. In addition, most mature seed bearing plants on firs are located within the crown of infected firs and not out on branch tips. Thus, lateral spread of mistletoe seeds outside the crown to other trees is limited. As a result, most of the new infections that occur develop inside the tree crown and within one or two branch whorls of the seed bearing mistletoe plant.

Consequently, young trees on good sites and trees that are growing an average of about a foot or more in height will "outgrow" the vertical spread of dwarf mistletoe (fig. 3). In addition, infections in trees in well managed even-aged stands contribute little to infection of adjacent trees. Of course, it must be kept in mind that infection levels will buildup in trees on poor sites, in suppressed trees, in overstocked stands or in young trees exposed to heavily infected overstory.

Mortality and Growth Impact From Dwarf Mistletoe in Young Managed Stands is Often Low

Recent unpublished studies by Scharpf on infested released red fir stands in California indicate that both mortality and growth impact

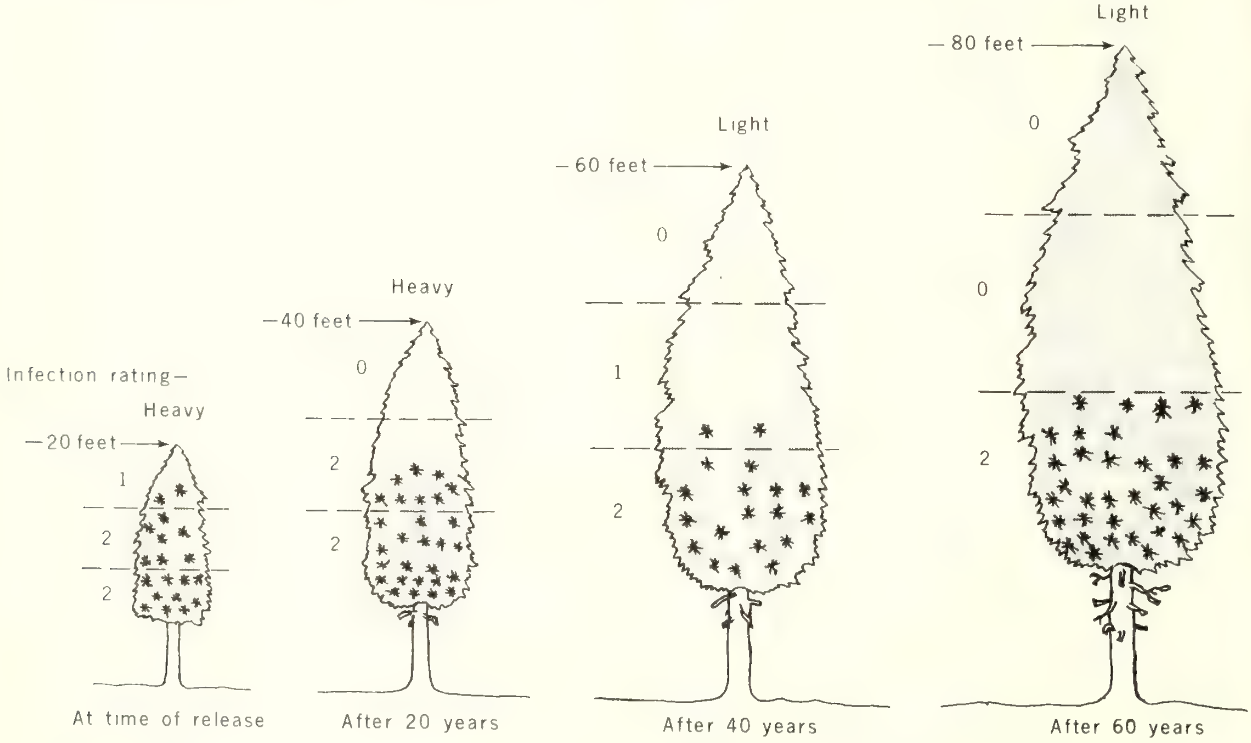

Figure 3--*Rate of vertical spread of dwarf mistletoe is less than the height growth for this released red fir (a hypothetical model).*

in infected trees is low and within currently acceptable management levels. Five years of study have shown that no mortality could be attributed to dwarf mistletoe irrespective of level of infection in any of several released red fir stands investigated. Where mortality from dwarf mistletoe does become a problem, as indicated by a recent USFS pest damage inventory, is when trees in infected stands are killed by a combination of two or more factors, such as, dwarf mistletoe, fir engraver beetle, *Fomes annosus* and *Armillaria mellea* (Byler 1975). Mortality from pest complexes is also higher than normal in dwarf mistletoe infested stands during periods of prolonged drought (Forest Insect and Disease Management Staff 1977). The canker fungus *Cytospora* also causes branch flagging and some top kill in firs weakened by both moisture stress and dwarf mistletoe (Scharpf and Bynum 1975). However, well released, vigorous fir stands with dwarf mistletoe have not shown above normal mortality on our test plots, even during the severe drought of 1976-77. Therefore, I question whether dwarf mistletoe caused mortality will be a major problem in well managed stands, even in combination with other pests or during periods of adverse climatic conditions.

Dwarf mistletoe affects the radial and height growth of red firs. But this effect may not be as severe as growth loss from suppression and other factors in unmanaged stands. Therefore, before dwarf mistletoe control is undertaken in young or second-growth firs, the stands should first be brought under silvicultural mangement; that is, increasing tree vigor commensurate with proper stocking levels and other management considerations. Release cutting in mixed size and age classes, thinning overstocked stands, brush control and possibly fertilization are examples of possible management approaches to increase vigor. Increased vigor automatically results in increased height and radial growth rates and reduction in the intensity of dwarf mistletoe. Any attempt to control dwarf mistletoe in unmanaged stands is not aimed at the heart of the problem and will result in wasted resources and effort.

In the management plan, how and when should dwarf mistletoe be controlled? To begin with, control initially need not be considered as a separate operation. A good deal of control will take place in the process of bringing stands into a well managed condition. For example, Gordon (1973) reported that noninfected young firs in California responded well to release cutting by increasing in height and radial growth. I obtained similar results in my studies of both dwarf mistletoe infected and noninfected red firs. Radial growth rate essentially doubled within 10 years after release for both infected and noninfected trees (fig. 4). Live crown ratio was an important factor in the subsequent radial growth of released trees (fig. 5). So long as trees, both infected and noninfected had a good live crown ratio, growth increased markedly after release.

The effect of release on height growth of trees was not investigated in detail, however, from field observations, I feel that height growth of infected and noninfected red firs also increases markedly after release. At any rate, height growth of study trees, even heavily infected ones, averaged more than a foot a year within 5 to 10 years following release (fig. 6).

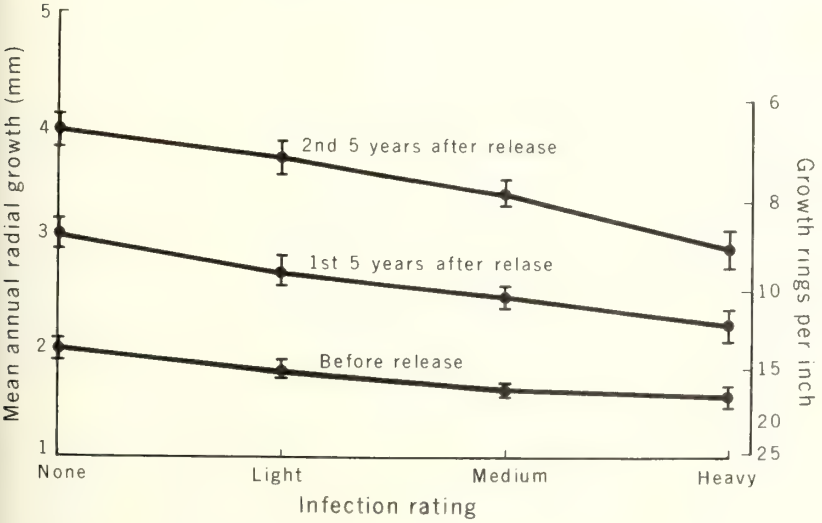

Figure 4--*Radial growth rate of red fir with various rated levels of dwarf mistletoe before and after release with 95 percent confidence intervals.*

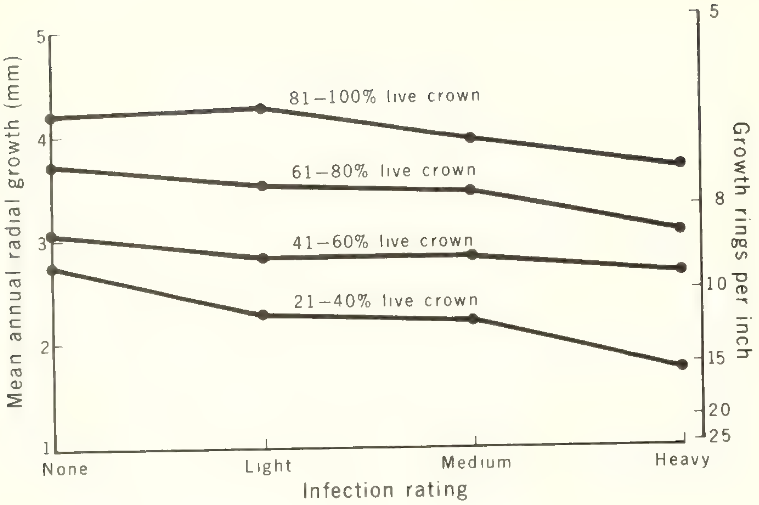

Figure 5--*Radial growth of red firs after release in relation to live crown ratio and dwarf mistletoe rating (10 years after release).*

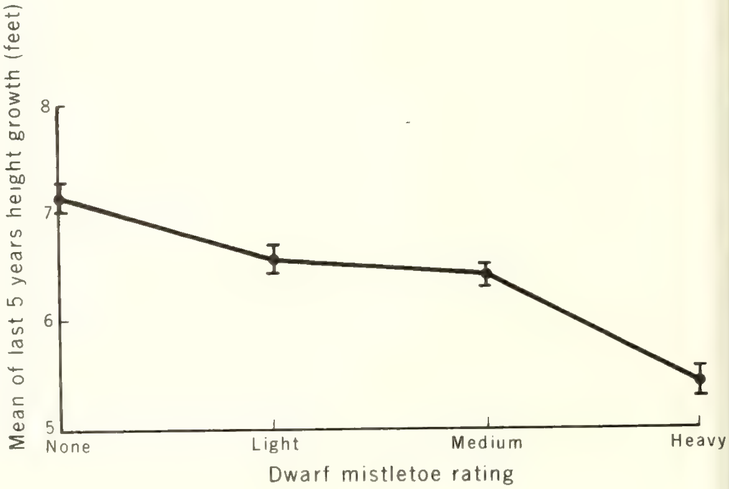

Figure 6--*Mean of last 5 years of height growth of released red firs in relation to intensity of infection by dwarf mistletoe with 95 percent confidence intervals.*

The maintenance of good height growth means that (1) over time, the parasite will be limited to the lower portion of the crown, (2) dwarf mistletoe intensity will diminish over time, and (3) any growth reduction caused by the parasite will become less and less severe in the developing stand. Of course, in releasing trees or in thinning operations, the manager has the option of further reducing impact from dwarf mistletoe by leaving the less severely infected trees as crop trees, as long as they have live crown ratios equal to or greater than the infested ones. Management of infested true fir stands for timber production in the situation I just described I feel will require no additional efforts, at least for the first rotation, to control dwarf mistletoe even though some volume loss may occur from dwarf mistletoe infection. Attempts at more complete control of the parasite should be considered in the final harvest and in the planning of the next generation forest.

One of the questions often asked by managers is: Won't dwarf mistletoe trunk infections in young firs develop into the large open, decayed bole swellings commonly observe on older trees in infested stands? My observ tions and unpublished results by Dr. Parmeter suggest that the large dwarf mistletoe trunk swellings commonly found on old-growth trees will not develop and become a problem in the management of dwarf mistletoe infested, secon growth stands. The cull and degrade commonly associated with larger bole infections on old-growth firs will almost certainly not be a problem in well managed, short rotation, secon-growth stands. In addition, recent studies I have completed have shown that dwarf mistletoe does not increase trunk taper in red firs as is often the case with heavily infested pines and some other species (Scharpf 1977). Thus, volume losses from increased tree taper is not expected to be a problem in infested, second-growth fir stands in the West.

One problem involving dwarf mistletoe in young stands that has not been fully investigated is the association between dwarf mistletoe and the canker fungus *Cytopsora abietis*. This fungus attacks and kills many branches infected by dwarf mistletoe. It could kill enough of the live crown in infected trees so that tree vigor and growth rate would be markedly decreased. Further studies to provide answers to this problem are in progress.

CONCLUSIONS

Control of dwarf mistletoe in true firs in the West shows promise because of the variety of management options,other than clear-cutting,open to forest managers. The primary consideration should be to get infested fir stands under good silvicultural management irrespective of the dwarf mistletoe situation. Good management should result in increased tree growth and vigor--and this will in itself reduce the impact of and problems caused by dwarf mistletoe and associated pest complexes. Efforts to control the parasite in true firs can be built into and implemented as part of the management plan for the stand. Development of the management plan should be based not only on timber management goals and the silvical characteristics of the stand, but also on the biology and epidemiology of the parasite. For the fir dwarf mistletoe, such planning requires understanding of parasite-host specificity, the age or size at which young trees become infected, the rates of growth required for firs to "grow away" from spread and buildup of the parasite, and the projected impact in relation to tree growth rates and dwarf mistletoe intensity. Armed with this information, the forest manager should be able to make management decisions that will be silviculturally sound and effective in the control of dwarf mistletoe in true fir stands in the west. As more information from research becomes available and as management of fir stands become more intensive, further refinement of control efforts to elimate losses from dwarf mistletoe can be achieved.

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[3] Verbal communication from J.R. Parmeter, Jr., Department of Plant Pathology, University of California, Berkeley, February, 1978.

LITERATURE CITED

Anonymous.
1972. Forest Statistics for the United States, by state and region, 1970. 96 p. Forest Service, U.S. Dep. Agric., Washington, D.C.

Byler, James W.
1975. Pest damage inventory In Proceeding of joint meeting of western forest insect work conference and western international forest disease work conference. p. 30-35.

California Forest Pest Control Action Council
1961. Forest pest conditions in California. Sacramento, Calif. p. 12

Forest Insect and Disease Management Staff
1977. 1976 and 1977 drought/pest caused tree mortality in national forests of northern California. Calif. Reg. Forest Serv., U.S. Dep. Agric., San Francisco, Calif. 8 p.

Gordon, Donald T.
1973. Released advance reproduction of white and red fir--growth, damage, mortality. USDA Forest Serv. Res. Paper PSW-95. 12 p., illus. Pacific Southwest Forest and Range Exp Stn., Berkeley, Calif.

Hawksworth, Frank G., and Delbert Wiens
1972. Biology and classification of dwarf mistletoes *(Arceuthobium)*. U.S. Dep. Agric., Agric. Handb. 401, 234 p. illus.

Parmeter, J. R. Jr., and R. F. Scharpf
1963. Dwarf mistletoe on red fir and white in California. J. For. 61(5):371-374.

Scharpf, Robert F.
1969. Dwarf mistletoe on red fir--infection and control in understory stands. USDA Forest Serv. Res. Paper PSW-50, 8 p. illus. Pacific Southwest Forst and Range Exp. Stn., Berkeley, Calif.

Scharpf, Robert F.
1977. Dwarf mistletoe does not increase trunk taper in released red firs in California. USDA Forest Serv. Res. Note PSW-326, 3 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Scharpf, Robert F. and H. H. Bynum
1975. Cytospora canker of true firs. U.S. Dep. Agric., Forest Pest Leaflet 146, 5 p. illus.

Scharpf, Robert F., and J. R. Parmeter Jr.
1967. The biology and pathology of dwarf-mistletoe, *Arceuthobium campylopodum* f. *abietinum* parasitizing true firs (*Abies* spp.) in California. U.S. Dep. Agric. Tech. Bull. 1362, 42 p. illus.

Scharpf, Robert F., and J. R. Parmeter Jr.
1976. Population buildup and vertical spread of dwarf mistletoe on young red and white firs in California. USDA Forest Serv. Res. Paper PSW-122, 9 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

PRESCRIBED FIRE - A TOOL FOR THE CONTROL OF DWARF MISTLETOE IN LODGEPOLE PINE[1]

S. J. Muraro[2]

This paper deals with the application of fire management principles to satisfy land management needs. What is fire management? Briefly, fire management is the application of fire related knowledge to achieve specific land management objectives. In this case, the required fire related knowledge is mainly ecological and fuel - weather - fire behaviour relationships. The overall land management objective is to establish healthy, optimally stocked stands to maximize fiber production. On areas infested with lodgepole pine dwarf mistletoe (*Arceuthobium americanum*) Nutt. ex Engelm., the treatment therefore has two specific objectives: sanitation and stand establishment.

It is not the intent of this paper to discuss the pros, cons or economics of mistletoe control but to suggest some techniques after the politicing and decision making has been done. I am presuming that the land manager has decided to institute a policy of mistletoe control or at least is evaluating the costs of various treatments subject to selecting a treatment. Prescribed fire, previously suggested by a number of researchers (Baranyay and Smith 1972, Donoghue and Johnson 1975, Gottfried and Emby 1977, Kiil 1969, and others listed by Alexander and Hawksworth 1975), is merely one of a number of tools which may be appropriate to the job. In the case of lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.), which is relatively easy to kill, and has a perpetual and ready supply of seed held in serotinous cones, fire has to be a strong candidate. If burning conditions are right, there is no cheaper way to cover an area than with fire; however, there may be either environmental or political restraints or unfavourable weather regimes that preclude operational use of fire.

Keep in mind, mistletoe elimination is an intermediate objective - the end objective is economical fiber production. With this in mind, cost comparisons of various treatments must include costs of stand establishment if the means of stand establishment are destroyed by the sanitizing treatment.

The specific area discussed in this paper is a triangular portion of the Interior plateau of British Columbia known as the Chilcotin, bounded on the east by the Fraser River, on the southwest by the Coast mountains and on the north by Highway 16. Latitudes 54°N and 51°N and longitude 122°W enclose the north, south and east sides, respectively. The terrain is gently rolling to flat, ranging in elevation from 700 to 1500 metres. Major drainages deeply dissect the plateau. The dominant forest cover on the plateau areas are multi-aged, multi-leveled stands of lodgepole pine, the result of extensive low intensity fires occurring at 20- to 40-year intervals. Each fire, in turn, thins the stand, prepares a seed bed, opens a varying number of serotinous cones and allows nonserotinous cones to open through increased exposure. The opened stand permits sufficient light to the forest floor to permit establishment of advanced regeneration which, in turn, is infected with dwarf mistletoe from the overstory remnants. Occasional small areas of denser, even-aged stands, indicating areas of higher fire intensities are scattered throughout the area. These even-aged, denser,more typical lodgepole pine stands tend to be free of mistletoe.

In general, these Chilcotin pine stands rank low on the spectrum of market value of lodgepole pine and because of the cold, dry climate (annual precipitation 429 mm ("16.5") growing sites are predominantly poor. However, the assigned site class based on height-age relationship of the current growth probably reflects to some extent the predominance of dwarf mistletoe. Notwithstanding, the generally low site classes suggest that forestry practices, especially those that require the longest term, such as sanitation and reforestation, should involve minimum investment.

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[1] Presented at the Symposium on Dwarf Mistletoe Control Through Forest Management, Berkeley, Calif. April 11-13, 1978.

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Judicious use of prescribed fire offers exciting prospects for meeting low cost sanitation and reforestation objectives for a wide range of control programs. Some of these techniques, most of which are not new, are applicable to other areas; however, they are particularly appropriate to the Chilcotin because of three conditions, (a) there is restricted or controlled fire use but not fire prohibition, (b) the areas generally do not involve conflict in value of understory and overstory species, and (c) low to moderate sites prevail, suggesting minimum capital investment for reforestation and sanitation.

In the Chilcotin generally all multistoried pine stands are infected. These stands are clearly evident on aerial photographs. Infected stands range from advanced regeneration on previously logged areas to overaged decadent stands and undersized immature. Because of the prevalence of mistletoe, some priority for control must be established. Recommended priorities for initiating mistletoe control projects from the standpoint of operational feasibility, lowest cost and administrative acceptance are:

(1) merchantable stands - stands that are currently in demand by operators, no inducements necessary.

(2) marginally merchantable stands - stands that are not in demand by operators and inducements to harvest are required.

(3) non-merchantable stands - stands that are definitely not merchantable now, nor in the forseeable future either because of extreme decadence, small diameter or slow growth rate.

Operational areas have been selected to provide combined research and demonstration units to evaluate the effectiveness and operational feasibility of fire use to achieve the dual purpose of sanitation and regeneration.

Merchantable stands (stands that are currently in demand)

From an operational standpoint, elimination of mistletoe from merchantable stands presents an absolute minimum of problems. The key to fire use in these stands is fuel management. Traditionally, at least in the Chilcotin, lodgepole pine stands are clear cut using feller - bunchers and full tree forwarding with grapple or choker equipped rubber-tired skidders. Topping and limbing is done either manually or by machine on the landing. This type of logging is favoured and has been advocated by fire protection interests and, except on winter logged areas, generally results in more than sufficient stocking. Waste piles at the lands are subsequently ignited during the late fall and allowed to burn out through the winter. This method is an extremely effective way of fuel hazard abatement; in fact, so effective that prescribed burning can only be accomplished in extreme burning conditions. The problem of burning these areas is accentuated by summertime grazing, which prevents the development of sufficient grass to aid fire spread. The objective of fuel hazard abatement was admirably accomplished and, if the silvicultural implications of nutrient removal can be accommodated, the practice should be continued where burning is not necessary. The acceptance of the broadened role of protection to include insect and disease, however, brings this fuel management practice of hazard abatement into conflict with requirements for the use of fire for mistletoe control. Thus the first task after acceptance of responsibility for a control program is to designate the specific area of each cutblock where control is necessary. Both the general and specific zoning of possible mistletoe areas can be achieved from aerial photos. The presence of open, fire thinned stands is almost a guarantee of mistletoe presence. The essential ingredient dictating the need for post logging sanitation is the presence of advanced regeneration. Remember these are not homogenous stands, and localized areas within a cutblock will support denser, even-aged stands that are mistletoe free or are too dense to permit advance regeneration. Such areas should be designated and ground checked prior to logging, because they will be difficult to distinguish from the remainder of the cutblock after the area is logged. If designated prior to cutting, they can be isolated by guards or roads integrated into the logging plan. Of course, the common sense perimeter measures recommended for mistletoe areas should be observed.

The key to achieving a fuel complex that favours fire use is to be aware of the requirement prior to selling the timber. At this time, the contract can be written to ensure that limbing either by hand or by mechanical means is done prior to forwarding. After about four weeks, the red foliaged lodgepole pine slash provides a fuel complex that will provide excellent fire coverage with minimum drying. This allows a land manager in virtually any climatic regime to achieve good sanitation with a minimum of ignition effort. A wide latitude of burning conditions are also available, dependent on the need for seedbed exposure requirements and fire control. Summer night burns, when adjacent timber stands will not carry fire, involve a minimum of ignition effort and low control costs. Treatment costs of less than $10 per acre should be expected. Fuel complexes that favour fire use can be created with lower costs because only useable material is forwarded. Savings in energy, landing expansion and cleaning and finally the need to burn landing piles is eliminated. Fire guard construction must be specified in the contract and completed while machines are still on the operation. Perimeter guards, one cat blade wide are sufficient for control. If care is exercised to ensure vehicular access, savings in perimeter mop up and patrol, using porta tankers will be possible. One pass, drivable construction is possible with a D7 or larger dozer at a rate of about 1 km (.6 miles) per hour; this equates to a cost of about $50/km ($80/mile). Mop up efforts will be minimized if waste from guard construction is pushed to the outside of the area and kept as low as possible. A clean inner perimeter will virtually eliminate hang fires at these critical locations.

Although excellent mistletoe sanitation can be achieved on currently logged areas by these simple techniques, there is a strong possibility that the seed in slash-borne cones will be destroyed and planting will be required. We know that fast spreading, short residence time fires can leave surviving seed both in slash and on advanced regeneration. Of question is whether it is operationally feasible. That is, is there sufficient latitude in fire behaviour between complete seed mortality and adequate stocking and good fire coverage to be operationally feasible. In the case of winter logging, where mineral seedbed is lacking, the longer fire residence period required to provide mineral soil suggests that all slash-borne seed will be destroyed.

There are, however, other alternatives for stand establishment; a seed tree cut followed by burning, or seeding of clear cut broadcast burned areas will be less costly than planting.

In any event, even with a token mistletoe control policy, the low cost of fire sanitation on future harvest areas must receive highest priority and should be conducted as routine procedure.

Marginal stands: stands that are not in demand and inducements to harvest are necessary.

The main difference between these stands and the merchantable stands is that extra cost either in stumpage allowance or direct subsidies may be required to induce harvest. Marginality may be due to low volume, small diameter, or decadence. These stands should receive second priority for treatment except if they occur on a particularly good growing site. If this is the case, then sanitation and rehabilitation should be initiated as soon as practical. If the growing site is favourable, then logging should be induced with subsidies if necessary and the fuel management practice suggested for the merchantable stands followed. Presumably the better growing sites are better able to show economic returns on the higher reforestation cost but greater success expected from planting.

If these marginally commercial stands are on poor to medium sites, then a least-cost treatment that accomplishes both sanitation and reforestation should be attempted.

Fire can be applied to accomplish both objectives in a variety of methods subject to constraints on condition and intended use of the harvested wood. If the stand is basically sound and processing includes chipping, then fire scorched wood must be minimized. In this instance, a seed tree cut leaving 20 to 30 trees per hectare will serve as the seed source. The fuel management practice of limbing on the area will provide fuel for good fire coverage to sanitize and adequate heat to liberate seed from the serotinous cones. This fire prescription must call for exposure of about 60% mineral soil and be of sufficient intensity to kill the seed trees. If mortality of seed trees is not achieved, they must be felled within three years.

If decadence is prevalent and long butting is required or if processing does not include chipping of mill waste, then underburning the stand using a controlled intensity surface fire will provide sanitation, seedbed and seed. Regulation of fire intensity is achieved by strip head fires and varying and distance between subsequent strips. The fire intensity required is dependent on the quantity of seed necessary to provide the desired stocking and the position of the cone crop relative to the flame zone. If the distance between the flame zone and the cones is large, little seed will be liberated; if the distance is small, a near maximum amount of seed will be liberated. Further stocking control can be exercised during the logging operations. If judged to be understocked, then tops can be left on the area; if satisfactorily stocked by the fire, then tops should be removed to reduce additional liberation of seed from slash-borne cones. Fire prescriptions for this procedure must ensure that about 60% of the area has exposed mineral soil if winter logging follows the burn. If the area is to be logged in the summer, then the exposure of mineral soil by machinery precludes the need for mineral soil exposure by fire. In this case, the prescription merely requires spread indices that will ensure good coverage and adequate intensities to affect the cone zone.

Non-merchantable stands: Stands that are definitely not merchantable now, nor in the future.

Treatment of these stands would be included in the most intense level control program. Not only does treatment of these areas incur full direct costs of control to the agency, they also involve the area of most uncertainty. Who can say for certain that a stand will not be merchantable or at least marginally merchantable in ten years' time? In some cases of extreme decadence or extremely heavily infected young stands, there may not be much doubt, but there will be instances of both types of stands that will be in a gray area. However, I started out by saying I wasn't going to deal with the "treat - don't treat" question. I repeat, we are in the treatment selection phase. It is assumed that the full cost of treating these areas will have to be borne by the land management agency without any immediate return. With this in view, not only should the worst stands be treated first to give as much leeway for error in future merchantability estimates but, also, the best growing site should receive priority. Treatment of these areas need not consider damage to material; however, it is important that the one shot effort achieve dual objectives of sanitation and restocking to desired levels. To achieve these objectives in both decadent and immature stands, the controlled intensity surface fire mentioned for marginal stands is used. Prescriptions must provide for sufficient fire residence time to provide either a very thin residual of organic material or exposed mineral soil to ensure a receptive seedbed. Most importantly, however, the prescription must achieve a high kill rate even at the risk of overstocking. Strip head fires serve as the seed release mechanism; but, in cases of young stands, flame length might have to be restricted to only two or three metres. The post burn microclimate of areas treated in this manner will be considerably less severe than that of logged areas. Shade will be provided by the remaining snags and, in addition, to immediate nutrient release from the fire, the needle cast will provide further nutrient and protection to the freshly fallen seed.

This treatment attempts to duplicate the effects of wildfires with two important exceptions. The modified intensity provides stocking control, and follow-up by hand felling crews removes the surviving trees to eliminate the source of infection to the new stand.

The cost of rehabilitation of these stands is relatively low if all objectives are satisfied and if 50 to 70 hectare blocks are treated. Cost of treatment will be most sensitive to the amount of hand felling required to remove residuals.

LITERATURE CITED

Alexander, M.E. and F.G. Hawksworth
1975. Wildland fires and Dwarf Mistletoes: A literature review of ecology and prescribed burning. USDA, USFS Tech. Rep. RM-14, 12 p. - Rocky Mt. For. and Range Exp. Stn. Fort Collins, Colorado.

Baranyay, J.A. and R.B. Smith
1972. Dwarf mistletoe in British Columbia and recommendations for their control. Can. For. Serv., PFRC Inform. Rep. BC-X-72. Victoria, B.C. 18 p.

Donoghue, Linda R. and Von J. Johnson
1975. Prescribed burning in the North Central States. USDA, USFS Res. Rep. NC-111, 8 p. North. Cent. For. Expt. Stn. St. Paul Minn.

Gottfried, Gerald J. and Robert S. Embry
1977. Distribution of Douglas-fir and Ponderosa pine Dwarf Mistletoes in a virgin Arizona mixed conifer stand. USDA, USFS Res. Pap. RM-192, 16 p. Rocky Mt. For. and Range Exp. Stn. Fort Collins, Colo.

Kiil, A.D.
1969. Basic considerations in the planning and use of prescribed fire. For. Res. Lab. Inform. Rep. A-X-21. Edmonton, Alberta. 11 p.

LOSS EVALUATIONS IN FOREST RECREATION AREAS[1]

Richard S. Smith, Jr.[2]

Abstract: We defined a set of management goals for recreation forest stands which say that we will attempt to maintain a healthy and vigorous, all-aged, mixed species, properly stocked stand with numerous old-growth trees. An infestation of dwarf mistletoe may well prevent us from reaching most of these goals. The dwarf mistletoes affect the trees both directly and indirectly through other pests. All dwarf mistletoe evaluations and control efforts should include consideration of associated pests. Recreation forest stands require proper silvicultural management for adequate disease prevention.

INTRODUCTION

Before we can consider some of the ways in which dwarf mistletoe infestations affect recreation forests we should recognize that there are several administratively different types of recreation forests. There are multiple-use forests, where recreation is a secondary use, and others where it is the primary use. There are restricted-use recreation areas, such as some wilderness areas, where forest management activities are not allowed, and other areas where various levels of management are required. Among these managed recreation areas are two general types: the dispersed recreation area, with or without secondary uses; and the developed recreation area, such as the campground, picnic area, visitor center, or other. It is mainly the latter areas -- the developed, intensively used, single-purpose recreation sites -- which we are usually concerned with when we talk about dwarf mistletoe effect on forest recreation areas, and it is mainly these areas I will discuss in this paper.

In this discussion, I will cover the goals of forest management in recreation sites, how dwarf mistletoe has kept us and can keep us from realizing these goals or make these goals more costly to achieve, some actual examples of dwarf mistletoe and associated pests effects in developed recreation sites and, lastly, forest recreation management philosophy and the prevention of insect and disease losses in forest recreation areas.

MANAGEMENT GOALS IN FOREST RECREATION AREAS

Before we can assess the adverse effects of a pest activity, we must first determine what our management goals are for the stand, area, or forest. The four southern-most National Forests in California, because of tremendous recreation use and pressures, have been designated as "recreation forests"; that is, they are forests where recreation will be the primary use and all other uses will be secondary, or not allowed. Because of this new responsibility in recreation, forest managers have pushed ahead in attempting to describe objectively and accurately the management objectives of a recreation forest. I personally am enthusiastic about their views and selection of management objectives in recreation forests and would like to use the goals they developed in our discussion of loss evaluations. These are:

1. Maintain attractive forests for recreational use and enjoyment.

2. Provide protection from excessive insect and disease losses.

3. Provide favorable conditions for maintenance of water flow and yield.

4. Reduce the potential for loss by uncontrolled fire.

5. Maintain and enhance wildlife and

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fisheries habitats.

6. Utilize trees removed from the forest in achieving the preceding goals.

7. Provide educational and interpretive services.

I would expect that these goals would be generally applicable to most forest recreation areas in the West. Managers at these southern forests also list second order objectives pertaining to stand management:

1. Maintain an all-aged or irregular sized stand structure.

2. Retain old growth trees as long as possible.

3. Control stocking to desirable levels.

4. Maintain mixed species composition.

5. Maintain healthy, vigorous trees.

6. Maintain a natural appearing stand.

The second order objectives are more specific and therefore are easier to relate losses against than are the more generalized primary objectives. You may view the stand management goals for your forest recreation areas somewhat differently, but for purposes of this discussion, I will use the above as objectives in describing the effects of dwarf mistletoe infestations on forest recreation goals.

EFFECTS OF DWARF MISTLETOE ON FOREST RECREATION GOALS

Having developed a set of primary and secondary goals, and using the more specific secondary goals, we can now look at how dwarf mistletoe infestations may prevent us from reaching these goals, or permit us to reach them at a higher cost. These goals and projected infestation effects are as follows:

Maintain an All-Aged Stand.

Infection of the overstory by dwarf mistletoe will result in the infection and eventual destruction of all, or most all, of the understory trees of the same and other susceptible species within the immediate vicinity of the infested overstory trees. The trend will be away from the desired all-aged stand toward an even-aged infested overstory. The real effect of this trend will usually not be felt until the last stages of stand development, when we find ourselves with an infected, overmature, thinning, even-aged overstory and few or no younger age classes which can be used to replace the decadent overstory. The forest recreation area is gradually denuded and loses much of its aesthetic value. At this point we may be left with the alternatives of either closing the recreation site or attempting to regenerate it slowly through a series of small selective overstory clearcuts and plantings. The attempt to regenerate the stand during the continued use of the site gives us the additional problems of coordinating our regeneration actions with recreation use and protecting our plantings from recreation-use damage. Either of the options -- to close the site and regenerate or to regenerate during continued use -- is costly.

Retain Old-Growth Trees

As trees age and move into the overmature age class, their vigor starts to diminish. Dwarf mistletoe infection adds additional stress to these trees causing them to decline in vigor at a more rapid rate. These declining trees are more susceptible to attack by bark beetles and other pests. Thus, the picturesque old-growth trees we wish to retain tend to die off more quickly if infected by dwarf mistletoe. In some cases, we can alleviate the stress by pruning the large, broomed branches -- caused by dwarf mistletoe infection -- from these trees. This is a costly operation and broom pruning often is considered undesirable by the landscape architects.

Control Stocking to Desired Levels

The recreation objectives of stocking control in an all-aged stand should be to maintain adequate cover (overstory) for shading, protection, and aesthetics, and sufficient understory and lesser vegetation for purposes of overstory replacement, screening, and aesthetics. The stand management stocking objectives should be to develop a stand which is not stressed by overstocking and which meets secondary objectives 1 and 2. Dwarf mistletoe infection of a stand may result in an understocking of the infested stand which is less than desirable or acceptable to the recreation stocking goals. The effects of dwarf mistletoe on the overstory is to put stress on the infected trees, increase their susceptibility to other pests -- particularly bark beetles -- and to cause the overstory to gradually thin.

The effect on the understory will be more dramatic. The rain of dwarf mistletoe seeds from the infected overstory will result in heavy infection of the understory and the direct killing of the susceptible trees by the dwarf mistletoe. The thinning of the overstory and the lack of replacement trees in the understory will result in the gradual decrease in stocking over time of the forest recreation area. Artificial regeneration with nonsusceptible species, or patch cutting of infected overstory and regeneration with susceptible species, are the alternative control procedures.

Maintain Mixed Species Composition

Infection of a tree species by dwarf mistletoe in a mixed conifer stand will tend to eliminate this species gradually from current and future stands. Infected overstory trees will be at a competitive disadvantage with overstory trees of other species. Susceptible understory species will become infected and die, and their removal will result in less species mix in the replacement stand. The elimination of a species from a mixed conifer stand will increase the stand's vulnerability to destruction by other pests and decrease its aesthetic value.

Maintain a Healthy, Vigorous Stand

The presence of dwarf mistletoe in a stand means that a portion of the stand is not healthy. The added stress brought on by this pest will result in decreased vigor of the infected trees and increased susceptibility of the stand as a whole to other pests, such as bark beetles. These other pests may build up on the dwarf mistletoe infected trees and from them spread out and infect or infest and kill trees not infected by dwarf mistletoe. Thus the dwarf mistletoe infected trees may pose more of a threat to the health and vigor of the stand than just the number of infected trees indicates. Secondly, dwarf mistletoe infections may provide for the entrance of other pests into the infected trees. Decay fungi frequently enter the older dwarf mistletoe bole swellings of true fir causing a heart rot, making the trees susceptible to stem failure, and thereby increasing the hazard to recreationists in these stands. Cytospora canker infects red fir at sites of dwarf mistletoe infections causing branch mortality. In many instances excessive branch mortality has further decreased the vigor of the infested stand.

Maintain a Natural Appearing Stand

Most recreationists would probably not notice an unnatural appearance until a stand has experienced a good deal of mortality and the stocking of overstory and understory were seriously affected. If this is the case, dwarf mistletoe would affect the other goals long before its effects would be felt here. Basically, I view the maintenance of a natural appearing stand as a key goal. I believe the purpose of the first five goals, in part, is to prevent our failing in this goal. And, if we do fail in achieving the other goals, it is only a matter of time until we fail to achieve this one.

COMBINED PEST EFFECTS

The effects of dwarf mistletoe on a stand do not occur alone. In real life these effects occur in combination with the effects from other pests. These other pests may or may not influence or be influenced by the dwarf mistletoe problem. Our evaluations of the dwarf mistletoe effects should include, therefore, an evaluation of the other pest problems, present or imminent. The dwarf mistletoe controls we institute must consider the effects of these other pests on the stand and the effects of our control procedures on these pests and the losses they cause. In the Forest Servic California Region, we feel so strongly about thi need to consider the total pest complex in a stand that we now are using a team approach in our pest evaluations. A basic team would include both an entomologist and a pathologist who would look at all major insects and diseases affecting the stand. To illustrate this need for teamwork I would like to describe briefly the pest evaluations we conducted this year on two very different recreation areas. In each case, dwarf mistletoe was a major problem and the pest evaluation was conducted by a pathologist, entomologist, and local forest manager.

Recreation Area A is a large area surrounding a lake and containing several campgrounds, picnic areas, summer homes, tracts, and considerable acreage for dispersed recreation. The stand is basically a young sawtimber overstory with a sapling understory, varying from absent to very thick. It is a mixed stand of ponderosa pine, incense cedar, white fir, sugar pine, and black oak. The overstory is heavy to ponderosa pine. Incense cedar predominates in the understory. Islands of old growth ponderosa pine are scattered throughout the stands. Last year the area experienced considerable mortality of ponderosa pine. A survey of the area revealed that 90 percent of the mortality was caused by a complex of insects and diseases. The major pests in this complex were dwarf mistletoe, pine engraver beetle, western pine beetle and Annosus root disease. Seventy-two percent of the dead trees had a Hawksworth dwarf mistletoe rating of 4, 5, or 6.

Thirty-eight percent of the trees had signs of pine engraver beetle attack and over 50 percent of the dead trees has been attacked by the western pine beetle. Overstocking was considered to be a contributing factor. The mortality was diagnosed as resulting from the combined effects of dwarf mistletoe, the two bark beetles, and overstocking. The prognosis was for additional mortality to occur in the near future resulting from the combined continued effects of these pests and Fomes annosus.

In planning for removal of the dead and partially dead trees, we had to consider the production of slash and its potential for creating another build up of the pine engraver beetle. In addition, over 60 percent of the dead trees still had green butts and root crowns which, when cut, would create stumps susceptible to infection by Fomes annosus. Annosus root disease centers created during previous sanitation-salvage cuttings were found in developed recreation sites. Stump treatment with borax was, therefore, a consideration in the control plan. With the prognosis for dwarf mistletoe and overstocking to stress trees and contribute to or cause future bark beetle problems, plans for a combined dwarf mistletoe-thinning program were also considered. The evaluation of area A identified four major pests, concluded that interactions between these pests did occur, and suggested control options in which all four pests and the losses they caused were considered. The stand is still young, with adequate stocking and a good species and age class mix. Much of the pest control could, therefore, be accomplished at little cost and disruption.

Stand B is an over-mature, mixed conifer stand with sparse understory and a thinning overstory. The stand is mainly ponderosa pine, Jeffrey pine, and white fir with occasional incense cedar and sugar pine. A survey identified dwarf mistletoe on ponderosa and Jeffrey pines, true mistletoes on white fir and incense cedar, air pollution, flatheads, Jeffrey pine beetle, fir engraver, and western pine beetle acting together in various combinations to cause most of the mortality. The stand has a long history of dwarf mistletoe and other pest problems. The prognosis was for continued mortality in the overstory and loss of the understory pines resulting in the loss of most conifers. Because the stand was so old, stocking so thin, regeneration difficult to establish and dying from dwarf mistletoe when established, stand management and pest management options were limited and costly.

Broom pruning of infected overstory trees was suggested as a means of reducing stress and lowering mortality in the near future. Other control options such as overstory removal, thinning, and planting would have to be tailor-made for small groups of trees and should consider species composition, all major pests present, tree vigor, and stand structure. The flexibility for control and stand management we had in Stand A is not available here in Stand B. But, the now younger Stand A could, without stand management and pest control, develop over time into a stand-pest condition similar to that of Stand B.

STAND MANAGEMENT IN FOREST RECREATION AREAS

Forest recreation stands are dynamic, interacting, growing, changing ecological systems. They are not static and will not remain unchanged regardless of our actions or inactions. These are statements I believe we can all accept on a biological basis. But we appear to have a problem accepting these ideas on a management and administrative basis. How many forest managers practice the same level of silviculture in recreation forest stands as in timber stands? Are recreation forest stands worth more or less than timber stands, and is the investment in maintaining these stands commensurate with the values placed upon them?

In the area of recreation stand management, we are still suffering from the effects of an older out-dated philosophy which advocated that man influence or affect the recreation site as little as possible so as to keep it "natural." This, of course, meant that we should do no stand management. We can no longer accept this older philosophy if we are to achieve the newer management goals described earlier in this paper.

Proper stand management and silvicultural management are the basis of an effective insect and disease prevention program in our recreation forest stands. The longer sound stand management is excluded from recreation stands, the more severe the insect and disease losses will become in these stands and, as we saw in comparing Stands A and B, the fewer and more costly will be our control options. This is particularly true of dwarf mistletoe problems where silvicultural controls are the most effective controls available to us.

Refining and Improving Control Techniques

COOPERATIVE RESEARCH AND MANAGEMENT EFFORTS LEADING TO BETTER CONTROL[1]

Richard S. Smith, Jr.[2]

Abstract: Past research-management cooperation done on a personal basis has been effective in providing us with the dwarf mistletoe controls we now use. Recent developments have brought us new opportunities to improve the control of dwarf mistletoe and other pests through increased cooperation between research, extension and management. The current stylized concept of the relationship among research, extension service, and management is inadequate to meet our future needs because it lacks the two-way flow of information, the flexibility, and the long-term closeness that will be required in the future. Forest managers, extension specialists and researchers should be encouraged and supported in long-term cooperative efforts in integrating the control of dwarf mistletoe losses with the control of pest-caused losses and with the intensive silvicultural management of stands.

INTRODUCTION

Talking about the merits of cooperation among research, extension service, and forest management is much like praising motherhood in that we all agree that it is good, that it is needed, and that it has been productive. And so I am not going to tell you about the past accomplishments of the cooperative efforts of researchers, extension specialists, and forest managers that led to the dwarf mistletoe control practices you now use. Instead, I would like to indicate where we now are in the area of research-extension-management cooperation, and what our future opportunities and needs are, and to describe some new ways or areas in which such cooperation can be more productive. And I hope that in exploring this subject together, we may all be inspired to cooperate with one another more often, in more ways, leading to more fruitful relationships.

This symposium was originally designed for and directed to forest managers and forest silviculturists. But in talking about the subject of research-extension-management cooperation it would be inappropriate to address just one member of the cooperative team. And since representatives of all three groups are here, I am addressing this talk to all of them. I do so with the thought that after my presentation, representatives from research, extension, and management will respond with their particular points of view so that we can start to develop more of an understanding of how we might better cooperate with one another to achieve our immediate and long-range goals.

Research-extension-management cooperation in the area of dwarf mistletoe control up to this point has resulted mainly from the efforts of several dedicated persons in each group. These efforts have been very productive, in fact in my judgment, they are among the most productive of the cooperative efforts in forest disease control. The organizations these people work for have supported these efforts financially and have generally encouraged cooperation on a personal basis. But they have usually not become involved to the point of setting specific organizational goals, assigning responsibilities and accountabilities, and evaluating progress toward these goals. I believe that these organizations do have roles in this area of research-extension-management cooperation beyond the general encouragement of such cooperation and that increased organizational involvement and dedication at all administrative levels will be needed if we are to meet the challenges of the future.

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[1] Presented at the Symposium on Dwarf Mistletoe Control Through Forest Management, Berkeley, Calif., April 11-13, 1978.

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NEED FOR RESEARCH-MANAGEMENT COOPERATION

Several conditions have recently emerged that, in my estimation, are going to require an increased sophistication, coordination and cooperation among forest research, extension and management if we are to improve on current and future operational forest pest control techniques and methods. Central among these conditions are:

1) A change in our goals from that of controlling pests and pest populations to that of reducing forest losses caused by pests.

2) An increase in intensive forest management activities and a corresponding increased emphasis on and availability of silvicultural control options.

3) The development of the dual concepts of pest complexes and integrated pest management.

These new conditions are responsible for changes in the operations and needs of forest pest management systems. And they are providing us the opportunities to strengthen our control methods through the coordinated efforts of forest research, extension, and management.

The thought that our goals in regard to forest pests should be to reduce the losses they cause is not a new one. It is a concept, however, that was over-shadowed until recently by the idea that our goals should be to reduce or control pest populations. Under this philosophy our efforts were usually aimed directly at controlling damaging pests so as to control a current epidemic by eliminating all or a large portion of the pest population. We talked in the now familiar terms of direct control, suppression, eradication, and, of course, pest control. The success of our control efforts was measured in terms of numbers of pests killed by or remaining after a control operation. Such evaluations usually were made shortly (1 to 3 years) after the control operation. Some of our early efforts in dwarf mistletoe control, in line with this philosophy, were aimed directly at this pest in an effort to eradicate it from stands by pruning and thinning. The effectiveness of these control efforts was based upon the number of dwarf mistletoe infections evident at the next stand entry a year or two later. Often a stand was worked 3 or more times in our efforts to eradicate this pest.

Reduction In Forest Losses

Recently our philosophy has undergone a slight but fundamental shift to where our goals now are to reduce forest losses that the forest manager finds unacceptable. Consequently, our control efforts must be evaluated on the basis of how effectively they reduce losses -- and not how effectively they control pest populations. Forest losses are no more difficult to measure than pest populations, but changes in losses resulting from control operations do require a longer period of time to express themselves. Such evaluations of pest losses must be based upon the goals and values of the forest manager. Thus, evaluations of pest-loss control must be made over longer periods, possibly a complete rotation and with the cooperation, assistance and guidance of the forest manager. And therefore, the development, testing and modification of control methods to reduce losses must be done with the cooperation of and input from the forest manager. The forest manager is needed to 1) define production goals and losses and 2) manage the test forest and keep adequate records so that a creditable evaluation of the control methods can be made -- one that will fulfill both research and management's needs.

The increased emphasis and great reliance on silvicultural control methods is going to demand a greater cooperative effort between the researchers, extension pathologists and forest managers. The development and testing of silvicultural control methods is usually done in a few, limited stand types and consequently the results of such tests are known to be applicable to only those types of stands within the test. Stands vary widely because of differences in age, structure, species composition, density, size, etc., and the initial research and operational testing of any control method cannot encompass all possible combinations of these variables. The research organizations have neither the time nor the resources to undertake responsibility for testing under so many varied conditions.

Limitations In Evaluation

On the other hand, forest managers who utilize the best information available and frequently employ control methods tested on other stand types do not have the time or resources needed to take the detailed information required to evaluate fully the control methods from the research or development standpoint. Usually what has happened in the past is that the extension pathologist has tried to meet the control needs of the forest manager by extrapolating as best he can from the available research information. Usually such control recommendations made to the forest manager have received only limited evaluations by the manager or the recommending pathologist or both to see if the manager's goals are achieved. Researchers and extension specialists who have tried to evaluate these operations some years later usually have found that the kind, amount, and detail of the stand and pest information taken both before and after such a control operation has been inadequate to meet their research and evaluation needs.

It appears quite logical that a cooperative effort between the forest manager, extension pathologist, and the research pathologist would go a long way in solving these problems. I am sure such cooperation has been discussed and recommended before. But it has yet to develop to the degree or in the amount we need if we are to do our part in developing the pest control portions of intensive silvicultural management systems. The cooperation between interested parties must be maintained over long periods for the successful evaluation of silvicultural control and prevention methods. All persons involved at all administrative levels must approve, support, and organize such cooperation if it is to be successful.

Pest Complexes

Within the last few years we have become more aware that our forest losses are not caused by single pests but more often by two or more pests working together to kill a tree. And in mixed conifer stands, total tree mortality is the result of several pest complexes working on different host trees or under different conditions. Control efforts against these major pests must be integrated with one another and with the silvicultural and management goals for the stand. And again, silvicultural and prevention type controls are the most desirable methods we see today.

If the long-term control of any one pest will require cooperation between the forest manager, the extension pathologist, and the research forester, imagine the complexity and the coordination and cooperation required for the simultaneous long-term control of several pests. To me, this will require more integration of the work of researchers, extension specialists, and managers than any of today's pest control methods. It is not a goal that we will reach easily or quickly. It is one that will require long periods of study and restudy as we attempt to fine-tune combinations of control techniques for greater effectiveness under varying ecological conditions. To do this effectively, the researchers must be active members of the planning and pre- and post-evaluation teams, and the forest manager must have a strong voice in the direction and goals of the research program.

COOPERATIVE RESEARCH-MANAGEMENT RESOURCES

What are the resources we have at our disposal to develop a more productive research-extension-management relationship? Broadly speaking, they are the people and organizations which have been with us right along. They are:

1. The forest managers representing Federal, State, and private forest land managing agencies, whose jobs are to manage the forests to meet the goals of their particular organization.

2. The extension specialist, including county agents, university extension pathologists, State forest pest control pathologists and Federal Forest Service pathologists.

3. The research pathologists and silviculturists from the universities and colleges and the Forest Service research stations.

As forest management intensifies and concepts change, these people and their organizations can and must find new and more productive ways to interact if dwarf mistletoe control operations are to be improved on the scale required by the forest manager.

DEVELOPMENT OF RESEARCH-MANAGEMENT COOPERATION

How do we use these resources most effectively in developing cooperative research-extension-management efforts and systems with the goal of improving dwarf mistletoe control? I am sure that management, extension and research each have valuable and constructive suggestions which would help to do just that. In fact, I might go so far as to suggest that in each geographic area we do get together to discuss just how research and management can cooperate towards improving dwarf mistletoe control and get administrative approval and support for the developed cooperative efforts. In the meantime, I offer these observations and suggestions:

First, the current stylized model of research-management cooperation is inadequate to meet future needs. It has neither the flexibility nor tenacity that we must have. This model is chiefly concerned with information transfer from research to management and often as not portrays this transfer as a unidirectional flow of information from research to management (fig. 1). This interchange between research and management is also viewed as temporary. When new research information is developed, research and management get together to field test it cooperatively -- often by means of a pilot control project. When the test is completed, they each go their own way.

This model may be adequate for this transfer of certain types of research information into management uses, but it does not meet our needs in the area of silvicultural control of dwarf mistletoes or other forest pest problems. The full integration of silvicultural control information into complex and variable biological systems requires the long-term two-way flow of research and management information. For example, we cannot hope to pilot-test new silvicultural control methods in many stand-site conditions. Using our best judgment, we will often be called on to extrapolate and use these new incompletely proven controls in new stands and site conditions. There is a real need to get the results of such an application back to researchers in terms he can use to evaluate its effects. The only way this can be done effectively is for management to communicate its plan to researcher so that he can plan and arrange to get the field data required to analyze these effects. This calls for closer long-term ties between research and management in a system which fosters and supports two-way communication and cooperation.

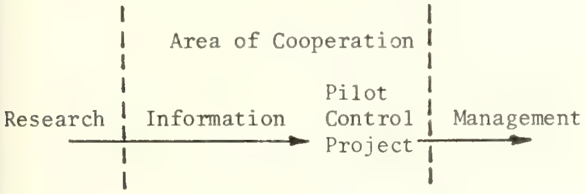

Figure 1-- Model of information flow and cooperation between research and management.

Establishing Two-Way Communication

This system of consistent two-way communication, up to now, has been difficult to establish except on a personal basis. The flow of information back to the researcher has been neglected for a number of reasons: 1) The field of operational silviculture is dispersed and dwarf mistletoe control is only one of a silviculturist's many concerns; 2) personnel turnovers are frequent and communication dependent upon personal contacts must be frequently re-established; 3) the need for two-way communication may not be recognized by either the research pathologist or the silviculturist; 4) recognition and reward for cooperation and accomplishments in this area is minimal or nonexistent; and 5) communication has to be extended over long periods of time before the results of silvicultural operations are known.

Other opportunities for productive research-management cooperation exist. Forest management organizations are rapidly developing more formalized methods of silvicultural operation combining periodic stand inventory, stand examination, written detailed silvicultural prescription and record keeping. In such a system, the stand is inventoried periodically (once every 10 years). These data are analyzed for basal area, basal area growth, mortality, potential crop trees, etc. The stand is examined for other site and stand factors, including such pests as dwarf mistletoes, and experts are consulted when and where needed. From the inventory and examination, stand management goals are defined and a written silvicultural prescription is prepared and implemented. The prescription is filed for reference so at the time of the next examination, the silviculturists may evaluate the effectiveness of the prescription against the goals set 10 years earlier.

This appears to be an ideal system into which, with the cooperation of the silviculturist, we could tie more detailed evaluations of pest control operations into a broader management planning system. The silviculturist could supply stand productivity information while the pathologist could supply the pest and pest control information. Together these two would make a more complete evaluation of the effectiveness of a control method which would form a basis for future stand planning and management activities.

Involving Research In Testing

Forest managers often do testing on their own without involving research. Here is another area where cooperation of research in the planning and evaluating stages would be very desirable. A forest manager is responsible for a living, growing and changing system which require or demand that certain decisions be made at certain times using the latest and best available information. Often this best available information is untested under these conditions but basic research, experience, extrapolation from use under other conditions, and/or logic indicates a certain option would be successful in preventing or controlling a forest pest. The forest manager may choose to use this unproven control method -- especially if as in many silvicultural control methods, the cost is minimal and the alternatives are undesirable. Here is a recurring situation in which those involved in research testing and extension type pilot testing may effectively and economically cooperate with the forest manager. But all too often the lines of communication are not open or have not been established and an opportunity is missed.

I am sure that there are many other areas in which research-management cooperation would be effective and productive. The challenge to us as forest managers, extension pathologists, research pathologists, and administrators is to support actively and build vigorously such cooperation in a way that will meet our current and future needs.

CONCLUSIONS

Cooperation between research and management has been effective in the past in developing operational dwarf mistletoe control methods Several recent changes have brought us new opportunities to improve the control of dwarf mistletoe and other pests through increased cooperation between research, extension, and management. They include (1) a change in manag ment goals for controlling pests to reducing losses, 2) increased opportunities in intensive forest management and the silvicultural control of forest pests, and 3) the development of the concepts of pest complexes and integrated pest management.

The current stylized concept of the relationship among research, extension service, and management is inadequate to meet our future needs because it lacks the two-way flow of information, the flexibility, and the long-term closeness that will be required in the future. Instead, the forest managers, extension specialists, and researchers should be encouraged and supported in their long-term cooperative efforts in integrating the control of dwarf mistletoe losses with the control of other pest-caused losses and in the intensive silvicultural management of stands in a variety of stand-site conditions.

REFINEMENT AND QUANTIFICATION OF DATA FOR REGULATING DWARF MISTLETOE POPULATIONS: AN ECOSYSTEMS APPROACH[1]

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Abstract: Some examples of existing quantitative data on tree growth reduction resulting from dwarf mistletoe infections are presented and evaluated. The need for accurate and reliable quantitative data is explained. The role of diseases in the plant ecosystem is discussed. Application of principles and concepts of plant ecology to control dwarf mistletoes in the ecosystem is advocated.

INTRODUCTION

Dwarf mistletoes (Arceuthobium spp.) cause some of the most important disease problems confronting managers of coniferous forests of western North America. These pathogens are not new. They are as much a part of our American heritage as the vast coniferous forests themselves. Their effects on our forest resources are viewed as problems to management of these resources because of the demands man has placed on the forests for goods and services. Recent estimates of timber losses attributed to dwarf mistletoes in the Western United States and Alaska exceed 3.3 billion board feet annually.

Despite the prevalence of dwarf mistletoes, many billion board feet of timber has been harvested from the Western United States since the arrival of the first settlers. As this country grows and its population increases, the demands on our forest land for both goods and services will increase proportionately. Simultaneously, the total area of forest land will decrease, giving way to higher priority use such as housing, highways, power line rights-of-way, reservoirs for hydro-electric projects, etc. The challenge is written. If societies are to continue to enjoy the pleasures and comforts of the many goods and services derived from the forest, then we must produce more and more of these amenities on a continuously shrinking forest land base.

While there are several options for meeting this challenge, one of the more viable alternatives is to maintain our forest lands in a state of high productivity. One of the more logical starting points for improving forest land productivity is to capture those losses to diseases such as dwarf mistletoes. Dwarf mistletoes provide a good example because their biology is well understood and their populations are readily amenable to management by several silvicultural practices.

The importance of dwarf mistletoes as pathogens in coniferous forests was demonstrated and recorded in the early part of the twentieth century (Weir 1916a,b). Foresters have been slow to realize the full extent of losses caused by these pests. There are several reasons for this situation. One is the fact that the Western United States was blessed with an abundance of coniferous forests. This is conspicuously evident today as attested by some of the issues and responses concerning accelerated cutting of the "surplus" growing stock on the Federal forest lands reported in "The Resources Planning Act: A Progress Report" (USDA Forest Service 1978). Until this decade, man has been content to occupy himself, primarily, with harvesting of these forests, deferring their perpetuation to the present generation of mankind.

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[1] Presented at Symposium on Dwarf Mistletoe Control through Forest Management, Berkeley, Calif., April 11-13, 1978.

[2] Principal Plant Pathologist, Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, Moscow, Idaho.

The second reason we have been slow to deal effectively with dwarf mistletoes is the dearth of quantified data that would enable the land manager to assess damage, determine needs for control, predict growth and yield, and calculate cost-benefit ratios of control operations for dwarf mistletoes. An enormous knowledge of these pests is available in the published literature, as papers already presented at this Symposium will attest. Perusal of this literature reveals that a perponderance of the information is documented in qualitative terminology. Furthermore, it is virtually impossible to transpose this information into quantitative terms because of limitations of time, purpose, and methodology of original data collection. This deficiency of effective quantitative data is especially conspicuous when one attempts to use systems technology such as computers and mathematical models as aids for land management decisions. Let us have a brief look at some examples of the quantitative data of dwarf mistletoe impacts that have been reported. You be the judge of its effectiveness with respect to today's needs.

STATUS OF DWARF MISTLETOE DATA

More than 60 years ago, J. R. Weir investigated many aspects of the dwarf mistletoes in the Pacific Northwest. During a period of some 15 years, he published evidence of the prevalence of these parasites and displayed a recognition for their capacity to damage coniferous forests (Weir 1916a,b; 1918). His many reports warned of the destructive nature of these pests. As early as 1916, Weir was recommending silvicultural measures for control of dwarf mistletoes in the national forests of the Northwest (1916c).

Weir (1916a) published one of the first reports of growth impact of dwarf mistletoes on western larch. Comparing average 10-year radial growth of 29 infected trees with 12 uninfected trees, he reported a 59 percent reduction in lightly infected trees, a 65 percent reduction in moderately infected trees, and a 84 percent reduction in heavily infected trees. The practical significance of these data is lost because of the tremendous age variation among sample trees (30 to 623 years) and Weir's failure to describe his criteria for classifying disease intensity. Another equally serious limitation of these data will be related later in this paper.

In the same year, Weir (1916b) reported on the growth impact of dwarf mistletoes in lodgepole pine, ponderosa pine, western larch, and Douglas-fir. The growth impact data are summarized in table 1.

Hawksworth and Lusher (1956) reported the growth impact of dwarf mistletoe on Douglas-fir in the Southwest. Mortality in all infected Douglas-fir stands was 4 times greater than in uninfected stands. Mortality in infected cutover areas was 4 times greater than in uninfected cutover areas and 2 times greater than in uninfected virgin areas. This loss was directly correlated with dwarf mistletoe intensities.

Unpublished reports by Graham (1956)[3/] revealed a 7-, 24-, and 47-percent diameter growth reduction for light, moderate, and heavily infected western larch, respectively.

Growth impact data from lodgepole pine stands in Colorado and Wyoming (Hawksworth 1958) showed 1.5 times greater gross merchantable volume in uninfected stands as compared to infecte stands. Mortality in virgin stands was 1.3 times greater in dwarf mistletoe infection area than in uninfected areas. Mortality in large poles was 5 times higher in infected stands as compared to dwarf mistletoe free stands.

Pierce (1960) studied the effects of infection intensities on total height and basal area in respect to site, age, and stand density. Although his sampling techniques were inherently deficient, his results are in general agreement with those previously reported.

A major limitation common to all these dat is the absence of a uniform and proven system for describing the environmental variation that existed within and between the test data. Wei (1916a) recognized the importance of ecology t the host-parasite relationship. He struggled to compare and explain the differences in the ecological amplitudes of Arceuthobium laricis (Piper) St. John and Larix occidentalis Nutt. It was a struggle because knowledge of plant ecological relationships was not so advanced a it is today and there were no proven systems for the ecological identification and classification of forest communities.

THE ECOSYSTEMS CONCEPT AND THE ROLE OF DISEASES

The individual plant constitutes the basi component of a plant community. Beginning as sprout, the plant is immediately affected by the actions and interactions of the many fluctuating biotic and abiotic factors of its envi ment. Each of these factors affect the plant simultaneously. Their individual effects upo the plant are modified and compensated for one another. The composite of their actions and i teractions is known as the environmental compl

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[3/] Records on file, Forestry Sciences Laborato Moscow, Idaho.

Table 1--Growth reduction of lodgepole pine, ponderosa pine, Douglas-fir, and western larch caused by dwarf mistletoes.

Host	No. trees	Average age class	Growth of infected trees as percentage of that in uninfected trees: Average height	Average d.b.h.	Average total annual growth
Pinus contorta					
Infected	50	65	72.6	80.8	31.7
Uninfected	50	60			
Pinus ponderosa					
Infected	50	100	64.1	82.0	28.9
Uninfected	50	100			
Pseudotsuga menziesii					
Infected	40	97	84.9	77.9	66.3
Uninfected	40	97			
Larix occidentalis					
Infected	80	144	55.0	59.0	59.0
Uninfected	80	144			

Environment is highly heterogeneous, even more so than most of us can conceive. Through eons of development, living systems have exhibited an expanding potential to adapt to environmental variability and change. Plants are no exception. Their accumulated features resulting from adaptation are well documented. Such adaptations result from interactions between the genetic constitution of the plant and natural selection activities of the environment. They may be genetically fixed or environmentally induced. While genes may function as templates for morphologic and physiologic features of living systems, their products are screened by a selective sieve--the environment.

The ecologic amplitude of plants is expansive but not unlimited. The plant has definite tolerance limits for each factor of environment. When variation in any single factor or combination of factors exceeds the tolerance limits of the plant, the plant will lose its competitive position. It will be discriminated against rather than selected by environment. Its vigor and vitality will decline. If this decline is unabated, the plant will become extinct in that environment. Thus, as a plant community develops, there is a continuous, gradual change in its physiognomy as a result of the rigors of environmental selection. We see the resulting community as a product of a multiplicity of interactions encompassing the total heterogeneity of environment and ecologic amplitude of the taxa represented. The plant community influences the environment and the environment influences the plant community. The two are inseparable.

I consider plant diseases as an integral phase of all plant ecosystems. They are actively functional factors of the natural selection process. Diseases constantly and continuously influence patterns of change, development and equilibrium of ecosystems. Simultaneously, every aspect of their behavioral patterns are conditioned by the functional activities of the ecosystem.

Some diseases are nonselective in their actions of altering plant communities while others reflect varying degrees of selectivity. In either case, the action of disease in altering these communities is largely incompatible with man's desires and objectives for managing the plants. Their significance to mankind is based mainly on land use. The conspicuous disadvantages of the unplanned and mainly unpredictable nature of disease actions masks any insidious advantages. Advantages do exist, however.

Effects of diseases upon development of vegetation are highly variable. The magnitude of variation becomes perceptible when one compares enphytotic with epiphytotic disease conditions, diseases caused by exotic versus indigenous agents, or the same disease in different environments. This variability is reflected in floristics, succession, physiognomy, density, dominance, distribution, vitality, and vigor throughout all successional stages, finding its ultimate manifestation in productivity. Indirectly, they strongly influence land use and management decisions.

ECOLOGICAL APPROACH TO MANAGEMENT AND SILVICULTURE

Success in production of goods and services from the forest to meet societies' needs of the future will depend on man's ability to develop and apply management practices that minimize the effects of diseases. To achieve this, we need to re-examine our thinking and expand our knowledge of just what really constitutes a forest. It is more than a stand of trees or a timber type. It is an association of plants that represents the current product of all the interactions of those plants and their environment. It fits the synecologic concept of an ecosystem. We must think in terms of managing entire ecosystems. We cannot succeed if we continue our attempts to manage certain segments, ignore some segments, and eradicate still other segments because the bonds of these segments are interlocking and indissoluble. Management practices to minimize the effects of disease do not exist, for many disease situations. In fact, many current practices optimize rather than minimize the effects of disease. Why do such situations exist? There are two prevalent reasons. Either we do not have the information necessary to develop the practices or we are not applying the information that is available.

In an earlier presentation, we heard silviculture defined as the art and science of culturing forests. The art was described as "flying by the seat of your pants" and the science described as ecology. In the past, we have perpetrated a lot of the former either under the disguise of the latter or the cloak of ignorance. What we need now is a better understanding and application of the latter. To be successful in this endeavor means that we must accept and intentionally project protection of the forest from diseases and other pests as an integral activity of silviculture. This can be accomplished by using the ecosystems concept as our approach to silviculture. This has not been the prevailing concept and attitude of the past and is a major reason why we are forever in trouble with forest tree diseases. Such an approach may be difficult to follow for some geographic areas of western North America because their ecology has been so drastically disturbed by man that their ecosystems have deteriorated beyond recognition. Fortunately, this is not the case in the Northern Rocky Mountains, Pacific Northwest, and Western Canada. Systems for classifying vegetation using synecological principles and concepts have been developed for these areas (Daubenmire and Daubenmire 1968; Pfister and others 1977; Franklin and Dyrness 1969; Krajina 1969) and assure us the opportunity to apply the ecosystems approach to the practice of silviculture.

INVENTORY

In order to properly manage a forest for goods and services, the land manager needs an appraisal of the total array of natural resources encompassed by the forest. This appraisal should be recorded in both qualitative and quantitative terms. The manager needs to know what he has to manage, where it is located and its condition. I view this as an ecological inventory of the natural resources to be managed; a recording of data that can be accepted as representing the present ecology. Our current inventory systems of gathering information for planning management action do not satisfy the needs of the land manager. This is one of the reasons he is "flying by the seat of his pants." The land manager himself should not be expected to develop the technology and decide what data to collect. This should be done in consultation and cooperation with a research organization that can provide input from persons possessing specialized skills and knowledge of forestry and related sciences. There is no need to collect data that has no utility.

DATA INTERPRETATION AND UTILIZATION

Another task confronting the land manager is understanding data in terms of plant growth and how he can use them to achieve his objectives. After all, data have little meaning and even less utility unless we can understand and explain their origin. Again, this task must be achieved in concert with research. If pest control strategies are required, they should be integrated with resource management activities. It is imperative that land managers and researchers work together on these activities and not independently and in isolation of one another as so often has occurred in the past.

Our ecological and silvicultural knowledge of ecosystems is very meager because of the intricate complexity of such systems. We have managed to collect and record some of the simple, easy, and obvious information of their functioning. As the information becomes more complex, corrections, additions, and continuation of this record will come more slowly and with increasing difficulty. How do we resolve this dilemma?

It has been suggested that we start with improvement and development of automated data processing and management systems that will efficiently handle infinite data entries (Waters 1975). Next, we need to develop the capability to integrate the interlocking fragments of data collected on functional factors of ecosystems. It appears that mathematical models composed of a series of differential equations can provide such capability. Such models are being developed and tested for the forests of the Rocky Mountains (Meyers and others 1971; Stage 1973, 1975) for growth and yield predictions of goods and services. Models to be used for predictive purposes and subsequent action programs, require exacting, accurate, and reliable, quantified data. Otherwise, they are reduced to just another system of generating guesstimates (Waters 1975). We have too many of these now. With such a requirement, one can readily reason why we are in a dilemma with the dwarf mistletoe impact data available.

In 1975, Intermountain Station's Research Work Unit 2205, Moscow, Idaho, established a study to quantify tree growth reduction in the Northern Rocky Mountain forests resulting from dwarf mistletoe infections. The objectives were to provide quantitative data for a dwarf mistletoe submodel to the prognosis model for stand development (Stage 1973) and to develop dwarf mistletoe growth loss curves. Preliminary analyses of western larch and Douglas-fir data are extremely encouraging for successful achievement of both objectives. It is interesting to note that these analyses show habitat type to be a highly significant variable ($P = 0.01$) affecting height growth. The field work is expected to continue for another 2 to 3 summers until the Northern Rocky Mountain forests are sampled.

Once acceptable automated data processing, management, and modeling systems are available, the forest inventory system must be updated. Inventory must provide the quality and type of data on the ecosystem needed by the land manager to effectively utilize the automated systems for predictive purposes and as aids to land management decisions.

SUMMARY

Continued increase of the population of man is rapidly becoming a burden upon the natural resources that sustain life by providing man with food and shelter. We are being challenged to increase productivity of goods and services derived from forests at an inopportune time when the total forest land base is rapidly shrinking. One way to face this challenge is to recover those losses in productivity due to pests. Pests that cause diseases are an integral part of forest ecosystems. Strategies to regulate the impact of diseases on forest productivity must be integrated with judiciously planned activities of managing the total forest ecosystem, not just a segment. We can no longer afford to operate in a realm of thinking where a forest is merely a group of trees and its pests are a completely separate entity. The efforts and knowledge of the land manager, the pest control specialist, and the research scientist must be coordinated and integrated into a systems approach to forest land management. This will require refinements and improvements in data collection, processing, interpretation, utilization, and application. More important, it will require recognition of and respect for ecological reality. Greater sophistication in automated data processing and mathematical modeling appears promising for enhancing our capability to process, interpret, and integrate the myriad of data needed to manage forest ecosystems as a renewable natural resource.

LITERATURE CITED

Daubenmire, R., and J. B. Daubenmire.
1968. Forest vegetation of eastern Washington and northern Idaho. Wash. Agric. Exp. Stn. Tech. Bull. 60, 104 p.

Franklin, J. F., and C. T. Dyrness.
1969. Vegetation of Oregon and Washington. USDA For. Serv. Res. Pap. PNW-80, 216 p. Pacific Northwest Forest and Range Exp. Stn., Portland, Oreg.

Hawksworth, F. G.
1958. Survey of lodgepole pine dwarfmistletoe on the Roosevelt, Medicine Bow, and Bighorn National Forests. USDA For. Serv., Rocky Mountain For. and Range Exp. Stn., Stn. Pap. 35, 13 p. Ft. Collins, Colo.

Hawksworth, F. G., and A. A. Lusher.
1956. Dwarfmistletoe survey and control on the Mescalero-Apache Reservation, New Mexico. J. For. 54:384-390.

Krajina, V. J.
1969. Ecology of forest trees in British Columbia. Ecol. West. North Am. 2:1-147.

Meyers, C. A., F. G. Hawksworth, and J. L. Stewart.
1971. Simulating yields of managed, dwarf mistletoe-infected lodgepole pine stands. USDA For. Serv. Res. Pap. RM-72, 15 p. Rocky Mountain Forest and Range Exp. Stn., Fort Collins, Colo.

Pfister, R. D., B. L. Kovalchik, S. F. Arno, and R. C. Presby.
1977. Forest habitat types of Montana. USDA For. Serv. Gen. Tech. Rep. INT-34, 174 p. Intermountain Forest and Range Exp. Stn., Ogden, Utah.

Pierce, W. R.
1960. Dwarf mistletoe and its effect upon the larch and Douglas-fir of western Montana. Mont. State Sch. For. Bull. 10, 38 p.

Stage, A. R.
1973. Prognosis model for stand development. USDA For. Serv. Res. Pap. INT-137, 32 p. Intermountin Forest and Range Exp. Stn., Ogden, Utah.

Stage, A. R.
1975. Prediction of height increment for models of forest growth. USDA For. Serv. Res. Pap. INT-164, 20 p. Intermountain Forest and Range Exp. Stn., Ogden, Utah.

Waters, W. E.
1975. Forest pest management: present prospectives and a look ahead. *In* Proc. Joint Meetings 26th WFIWC and 22nd WIFDWC, Monterey, Calif., p. 11-14.

USDA Forest Service.
1978. The Resources Planning Act: A Program Report. USDA For. Serv., 52 p.

Weir, J. R.
1916a. Larch mistletoe: some economic considerations of its injurious effects. U.S. Dep. Agric. Bull. 317, 25 p.

Weir, J. R.
1916b. Mistletoe injury to conifers in the Northwest. U.S. Dep. Agric. Bull. 360, 39 p.

Weir, J. R.
1916c. Some suggestions on the control of mistletoe in the National Forests of the Northwest. For. Quar. 14:567-577.

Weir, J. R.
1918. Effects of mistletoe on young conifer J. Agric. Res. 12:715-718.

IMPROVING EXTENSION AND TRAINING PROGRAMS

FOR

DWARF MISTLETOE CONTROL[1]

Kenelm W. Russell[2]

Abstract: Integration of dwarf mistletoe control into forestry planning and operational activities is stressed. A survey indicated that managers are concerned about disease control. Their needs are identified with regard to dwarf mistletoe control. Suggestions on conducting training sessions include hints on good slide or slide-tape and graphic preparations. Guides for smooth field trips (take a bus,not 40 cars), oral presentations (what to do about jitters) and written material (quick reading comprehension test) are presented. Field aid preparation, timber sale clauses to reduce dwarf mistletoe and a sample sanitation-thinning contract are also included.

A major problem facing pathologists regarding dwarf mistletoe control is that they are so few in proportion to the millions of problem acres. Approximately 60 field pathologists must devise all manner of ways to spread themselves thinner in order to train the greatest number of forest managers in control methodology.

There are a variety of ways to put this message across. But, no matter what, the approach must be interesting, straight forward and well presented. Fast moving slide presentations at staff meetings or special workshops combined with field trips; written, illustrated guides; demonstration plots in regional areas and pocket field aids are all effective methods. Group size might range from this symposium to "one on one."

Perhaps the best thing about dwarf mistletoe control is that it can be programmed into any existing timber management system without a great deal of expense in either training or operations. In these days of the rapid move to intensive forest management, reduction of dwarf mistletoe is (for certain stands) as good a means to increase production as fertilization or thinning. The parasite reduces growth while thinning and fertilization increase it. Wouldn't dwarf mistletoe removal give similar overall increased growth?

Dwarf mistletoe has several characteristics which aid in developing positive control attitudes. It is a highly visible parasite, not a mysterious underground root disease. It has large visible seeds traveling known distances, not microscopic spores traveling on the whims of the wind. It spreads slowly (except for bird or animal spread), not rapidly or over wide distances like the seemingly hopeless blister rust. It can be controlled silviculturally. All aspects of the disease can easily be understood by a layman.

Effective training is a prerequisite for stimulating good dwarf mistletoe control attitudes regardless of owner. Such attitudes do not develop overnight. Sometimes it takes years to thoroughly infiltrate bastions of resistance within a management team. The old guard is naturally skeptical at first. It's a sales job! The training group must culture "disciples" in the field, who, upon becoming dedicated "DM control nuts" serve to "infect" their cohorts. They in turn spread the word to bosses, underlings and peers alike.

I have gone away from the complete "everything you wanted to know about all diseases" discussions. I now use highly animated, rapidly moving staff presentations, covering only one or two diseases or disease control aspects. I believe it is better to saturate smaller groups with less material, more intensively presented. Normal district or management staffs of 10-20 persons are ideal. I like to come back to the same staff many times with different material. Over time, the trainees become interested authorities.

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[1] Presented at the Symposium on Dwarf Mistletoe Control Through Forest Management, Berkeley, Calif., April 11-13, 1978.

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INTEGRATING CONTROL

All dwarf mistletoe control training must be integrated with other forest management activities. The overriding philosophy must be well in hand first. The manager must ask, "Can I eradicate it?" (evenage management, clearcut), or "Should I reduce it to a level that allows good volume production?" (unevenage management, sanitation-thinning).

The two following examples illustrate how integration of planning and control operations might work:

It is important to note that dwarf mistletoe is not compatible with two-storied or multistoried stand management. In unevenage management, the primary objective should be to control dwarf mistletoe in the infected overstory. Therefore, timber sales should be planned with this objective in mind. Sanitation of the understory follows. The order should not be reversed.

Where recreation and forest management objectives conflict, modification of control principles often must be made to satisfy both uses. In South-central Washington, the Department of Natural Resources retained a narrow corridor of infected old growth ponderosa pine leading to a scenic canyon. The forest surrounding the corridor was marked for overstory removal to reduce the dwarf mistletoe. The corridor and horse trail down its center lead to a scenic outlook. Future recreationists will appreciate the retained trees which could be pruned if necessary. Impact to timber management will be minimal.

Mindful of varying objectives, the manager must be trained to fit dwarf mistletoe control into context and even use it to advantage. For instance, he might reason as follows: "Can I use some of that infected overstory to regenerate the stand?" How soon must I remove the overstory to avoid infecting the regeneration?" The manager might also ask, "How can I 'dwarf mistletoe proof' this stand? Will periodic prescribed fire help me?" I believe it will, but it must be done at the right time under proper conditions. Once the manager is trained to ask the right questions, the control success will come naturally. Realistically, this manner of thinking does not develop overnight.

Forestry schools have traditionally taught forest entomology, pathology and fire courses separately from silviculture. Except in rare instances foresters are left to their own devices to merge these subjects to provide answers for complex management decisions. Not all foresters do it. Not even all foresters take the courses mentioned above. Minimizing one pest might encourage another. It's like trying to submerge 100 ping pong balls in the bathtub simultaneously. There is need for a single integrated course, perhaps utilizing team teaching, that brings elements of silviculture together with entomology, pathology, fire and even ecology into a totally integrated approach. My bet is that students would find it fascinating. This same approach would also make a challenging and interesting regional symposium.

WHAT DOES THE MANAGER WANT?

Audience

It is important to know your audience. How much do they know? What do they need? What do they want? What is their background? How many will receive the training? Your approach and intensity will vary with the audience. Tailor the material to the group; for example, do not talk about details of larch mistletoe to coastal Oregon foresters. View every meeting with a forester as a training opportunity. Ask participants beforehand what they want.

The Pacific Northwest Forest Pest Action Council (Russell, Howard, Weir, Johnson and Nelson, 1975) conducted a survey to help determine priorities of forest diseases in the Pacific Northwest. Comprehensive questionnaires were sent to the region's forest managers asking them to assign priorities to forest disease groups. A section of the resulting booklet was devoted to miscellaneous written comments returned with the questionnaire. A few of these with slight edit to emphasize dwarf mistletoe control are worth repeating here.

"The majority of forest disease research publications and surveys I read are informative but do not help me in my day to day silvicultural decisions."

"Literature reviews and experimental designs are great but not for busy field foresters. Tell me briefly what you did and how it applies to management."

"Write in plain, simple English!"

"Provide a clearing house for information."

"What is the impact of dwarf mistletoe on allowable cut calculations?"

"We need simplified economic justifications for dwarf mistletoe control."

"Make sure the material provided pertains to solutions for the man on the ground."

"How can we handle dwarf mistletoe in shelterwoods?"

The above statements clearly indicate the vein of content needed for dwarf mistletoe control training.

PREPARING THE TRAINING SESSION

Material

Know your stuff inside out. Include interesting biology if it ties in with management. Have access to all mistletoe literature. Know who the experts are and consult them--have them review material. Update as required. Consult texts on making presentations.

Coordinate training with other area pathologists so everyone gives essentially the same message. Schedule training to avoid conflicts with foresters' crunches like planting and fire seasons. Evaluate the success of any training effort to identify areas needing improvement.

When foresters come to a training session, they want something to take home. Make the subject matter apply to specific aspects of their jobs. Above all, provide useable information that can be taken home.

This is why I prefer the repeat appearance covering different disease groups each time. I learn more about the problems managers are having this way. I begin to get a feeling for their needs. I also learn about conflicts with controlling groups (other Divisions) that may suppress (not necessarily intentionally) what I'm saying. These types of sessions allow the pathologist and clientele to form a better two-way avenue for exchange.

One failing (I'm guilty too!) is not allowing time for adequate discussion. There have been times when meaningful discussions were twice as long as the presentations. It wasn't planned that way.

Slides

A variety of visual aid equipment is available. Unfortunately, instructors don't always use aids to full advantage or quality. Well prepared slides are most effective and hard to beat. Seek and use professional advice in making slides. There is no quicker way to lose a group than to say "Sorry you can't make this out back there . . . ." If a slide cannot be easily read at normal reading distance of 12-14 inches, then the print is too small. Toss it! Commercial artists are a big help if you are short on artistic ability. There are several excellent publications on preparing slide presentations. Consider multiple projectors for larger audience talks.

Always ask these questions during preparation of your presentation. "Is there too much detail on one slide? Did I cover only one point at a time? Can I use a series of slides adding one point at a time to build a story?" Move on rapidly (only a few seconds per slide). If you keep points simple, the listener takes more home and retains it longer. Weyerhaeuser Company's professionally prepared graphic slides are excellent examples to follow. Their high quality is known and appreciated all over the Northwest.

If you are short a critical title or data slide and the talk is tomorrow morning, try this! Type the words or data needed on an A. B. Dick stencil or a sheet of onion skin. Cut the paper or stencil to fit a slide blank. Press it in with a warm iron. The stencil gives a white letter with a neat fibrous blue background. The onion skin gives a black letter with gray background. The same could also be done using a copy machine to produce a transparency (similar to one for overhead projection). Black letters with clear background result, or, if colored plastic is inserted in the slide holder, any background color could be obtained.

There are advantages in using this method; the letters are very large, the process is quick (minutes) and the small slide with regular typing limits copy to a single word or a few words or numbers.

Slide-tapes

An advantage of the slide-tape is that they can be viewed at any convenient time. Often, the persons who really wanted to hear the presentation were probably out hustling logs when it was given. Upon return, they can retire to a dark room and digest the material. The program can be stopped, studied or repeated.

The average slide-tape show is appropriately geared to the 80 or 100 tray Kodak Carousel. Use of the 140 slide tray is not recommended for any large group presentation. The least little "dog ear" on a slide may cause it to hang up - an embarrassing situation. A full tray or less is recommended per single program with a tape. A full tray of fast moving slides can be utilized in a 12-14 minute presentation. Anyone can operate the equipment. All that is needed is the projector, a good quality cassette tape recorder (such as a portable Bell and Howell educator model) and a listener. The high quality portable recorder can be used in a large room for as many as 50 people. The $29.95 "special" recorder is definitely not recommended for this job. More sophisticated equipment is also available.

Consider the possibilities of background music and a professional narrator. Most organizations have access to both. Slide-tapes are easy to produce. They have a definite value in effective training.

One of the best slide-tape programs available is Rx for Wounded Trees (Shigo, 1976). It tells the story in 80 concise, well designed and illustrated slides. Anyone can understand it. It has music and was professionally narrated. It could be used as a guide for a slide-tape on dwarf mistletoe.

There is one pitfall that can occur during production of a program. There seems to be a point during its production when it is "just right." Learn to look for and sense arrival of this point. I have seen examples of a fine program or film ruined by tampering because the author wanted to "improve" it. There is quality in simplicity.

Field Trips

Have them well planned. Confusion on a field trip or lost people causes chaos and dissention. Pick sites carefully before the session. Group stops to avoid long travel. Use a bus instead of 40 cars. Use signs to describe the attractions; e.g., This is larch dwarf mistletoe. Make walking easy; remove the brush. Use research plots where applicable. Establish demonstration plots complete with signs. Allow plenty of time. Provide written descriptions of problem viewed.

MAKING THE ORAL PRESENTATION

Audience

Do not talk down to the audience. Join right in at their level and use vocabulary the will understand. Humor, cleverly worked in is good but don't overdo it. Dress neatly but don't come on like a dandy. Have the best person do the training. Put the green employee in the audience to learn. Do not worry about saying, "I'm sorry. I don't know, but I'll try to find out." Invite someone who is a good stimulator of discussion.

Involve the audience in the learning process. Ask them questions. Even let the audience do some of the teaching by asking the leading questions. This method is very succes ful but takes practice. Be dynamic but not hi pressure or overbearing.

Equipment

Know your equipment. Slides backwards? Can you change a bulb? In the dark? Where is the light switch? Can you fix a jammed Carousel? (Use a coin to turn the release screw in the center, lift the tray off, extrac the offending slide, turn the tray upside dow and rotate the metal plate until it clicks bac into place. Reinstall tray.)

Meeting Room

Become familiar with it. Are there obstructions or other peculiarities? Start wit it cool and plenty of fresh air. Each human gives off approximately 100 watts of heat. On hundred people will heat the room several degrees before you are through. Sense your audience's mood. If they are overly relaxed maybe you should take a break or at least a quick stand-up breather. Also take this oppo tunity to refresh the air in the room.

Jitters

Relax and plan on them. They help you give a good presentation. Everyone has butte flies - even politicians and actors. They co in a variety of ways and timing. Fear of failure helps make a good talk. You have one thing going for you. Outward signs of stage fright are hard if not impossible to detect. Your knees can be knocking so hard you can hear them. No one else will know! If you faint dead away though, heaven help you! When you're up there all alone with bright lights and facing that formidable audience, the shakes almost always disappear.

PREPARING WRITTEN MATERIAL

Written material for schedule bound forest managers must be short. Avoid extraneous detail. Scientific writing "turns'em off." It doesn't hurt to begin a written guide with a few topic sentences detailing the contents. No jargon, complex sentences or long dull paragraphs allowed. Did you ever face a one page single spaced letter consisting of one paragraph? Ugh! Get a frank and extensive review of your production before putting it out.

I once heard a writing consultant who advised two simple criteria for judging readability. He counted average sentence and paragraph length in professionally prepared articles. Sentences should average 13 words and paragraphs should be no longer than 9 lines for easy reading comprehension. He further advised that this pattern is ideal for 8th grade readers. Now I don't wish to insult managers and scientists alike, but using this approach makes the reading faster and more comprehensive. Anyway, I liked his advice. There are more complex methods available to judge readability, but the system described here is simple. Try it!

I counted 18 consecutive sentences in this report and found my sentence length averages 15.6 words. Shooting for 13 and allowing for extra wind brings the average up, and my readability level increases a bit. Try digesting an article that averages 26 words per sentence. Your head will swim! Maybe you've even written a few. Count the average words per sentence in one of your insurance policies.

How about using the newspaper column pattern? The human eye reads best in short bursts across a page. Newspaper columns are about 2.5 inches wide, the distance for optimum eye movement and smooth reading. Secretaries can type double columns quite easily on standard size paper.

How attractive is the written material? Pictures help and today's copy and multilithing ease make the use of pictures a simple process. Consider including color or using professional illustrations. For written material to be produced in limited numbers, try color copying machines. Their quality is amazingly good and cost is relatively low compared to color printing processes.

Will the forester who is worried about ordering parts for a broken bulldozer read your production while waiting for the busy phone line? If so, it is probably worth reading. Spending time doing professional eye-pleasing layout is well worth the effort. Do not be afraid to spend money on your effort; it can pay big dividends.

Provide interesting reading laced with a few unusually put but easy to remember biological facts about dwarf mistletoe (below). Excerpts taken from training material on hemlock dwarf mistletoe control show an attempt to do this (Russell, 1976). Note short sentences, paragraphs and simple easy to remember facts (60 MPH, 40 feet of the plant, 10 well dispersed infested trees).

"The mechanism of seed firing is one of the most interesting in the plant kingdom. It resembles NASA technology. As the wheat grain sized berry or capsule matures, the stem curves downward and elongates. The capsule orients to the brightest light with point down. The special viscin (a glue-like substance) filled cells between embryo and capsule become primed with pressure. At the moment of blast-off the capsule falls away and the single viscin coated 2-3 mm long seed propelled by highly pressurized viscin and water 'fuel' ejects from the attached end of the capsule. It arcs away into the sunlight trailing a 'contrail' of glue and water. 'All the other seeds cheer.' Night firings are conducted also, but at a much reduced number."

and further on . . . . .

"Most seeds fall within 40 feet of the plant. Maximum seed distance is about 60 feet. Wind can affect seed distribution. Smith showed that almost 70 percent of the seeds were trapped in the southern sector. Density of the stand and the branches of the host tree influence distance shot. 'Muzzle velocity' of these unique seeds is about 90 feet per second, or roughly 60 MPH. Seed bearing plants tend to orient as much as possible to brightest light source. On warm fall days, low sun offers optimum firing angle. A study of seed germination and infection found that 18 percent of A. tsugense seeds that were tagged in the spring caused infection. This did not account for those lost during the winter."

"A single western hemlock overstory tree is capable of dispersing seeds over about 6000 square feet. This means that fewer than 10 well dispersed infected trees per acre could potentially infect all new or existing regeneration."

Forest Management Manuals

The Washington State Department of Natural Resources Manual contains sections on dwarf mistletoe control. Since western hemlock dwarf mistletoe Arceuthobium tsugense occurs only west of the Cascades, it has a separate section of the manual. It stresses simply, clean clearcuts. (The commonly used skyline, balloon or helicopter systems do not destroy advance regeneration and special treatment may be necessary to reduce the parasite.)

Manual guides for eastern Cascades dwarf mistletoe control are treated separately because management there is generally uneven age. Instructions for marking timber sales are contained on only two pages. The guide for treating young stands after infected overstories have been removed is not completed but will be equally short.

Field Aids

The WDNR maintains a set of field aids for all district personnel. They provide a condensed manual prepared on waterproof paper in a vest pocket size notebook. They make use of tables and line drawings to get the point across. Two or three pages of these will be prepared for various aspects of dwarf mistletoe control. Only limited biological detail will be given as this information is available in manual references. Field personnel like these quick self helps.

A wallet card is also used by WDNR that is patterned after one prepared in the Southwest by the Forest Service. It is intended for use by pre-commercial thinning operators.

Rules for spacing crop trees and rating infected cut trees are indicated. It is important that simplicity be uppermost in preparing any of these types of field aids. Some of the operators are barely literate.

One of the main reasons for the wallet card is that the unit administrator and the operator can discuss "leave or cut" tree criteria using concrete guides. There is little or no argument between a trained forester and the operator about whether an infected tree should be cut. The simple rules will tell them. Ambiguity is removed.

Contracts

In a way, timber sale contract preparation functions as a training help. The WDNR contracts are made up using a series of carefully prepared clauses that, when assembled, describe the contract. The manager using his guide merely lists the clause numbers desired. One such clause is shown below. It can be used for a variety of purposes including dwarf mistletoe control.

Non-merchantable Trees

"Within areas to be clearcut, all live trees (over ___ft. in height or over ___inches in diameter), excepting such areas of young or immature timber specifically designated by the State, shall be felled concurrently with the logging operation."

Instructions--"To be used when broadcast burns of clear cut areas are planned and it is desired to have all of the non-merchantable trees felled to accomplish a more complete burn. Also for the felling of undesirable or diseased residuals to be disposed of prior to site rehabilitation. The cost of this work must be provided for in the appraisal."

Contract description and instructions for a typical non-commercial thinning--dwarf mistletoe sanitation unit follow:

District

Omak Unit: 15-9

Name of Thinning

Irene Mountain

Contract Supervisor's Representative

Joe Bnox

Approximately 91 net acres in Section 16, Township 38 North, Range 31 East, W. M., require treatment. Douglas-fir, ponderosa pine, western larch and lodgepole pine species are on this unit. The unit boundary is well defined with fence and ribbon on the north, ribbon on the east, fence and ribbon on the south and ribbon on the west. The unit topography is level to 50 percent slope. Unit has year-round access. Approximately 475 stems per acre are on this unit, and approximately 305 stems per acre will be mechanically treated to maintain an average of 170 trees per acre at 16 x 16 foot spacing. The average d.b.h. of the trees to be mechanically treated is 3 inches. Dwarf mistletoe is to be removed as described in the following instructions.

Period of Contract

This contract shall terminate June 15, 1978.

Buffer Zone

All slash within 100 feet of the county road and within 50 feet of all other truck roads shall be piled. Piles will be placed so that they can be burned with the least possible damage to standing trees and young growth.

Leave Tree Specifications

Areas Or Tree Groups Free of Mistletoe Infection--All conifer trees larger than 6 inches d.b.h. are designated as crop trees and are to remain.

Crop or leave trees in addition to those designated by size, are to be selected by Contractor at 16 x 16 foot spacing.

In any area more than double the spacing across that does not have a crop tree identified by size, Contractor shall select and leave uncut the largest live conifer trees of good form and vigor that will maintain average specified spacing.

Areas Or Tree Groups Having Mistletoe Infection--All uninfected conifers larger than 6 inches d.b.h. are designated as crop trees and will remain.

Uninfected conifers smaller than 6 inches d.b.h. designated as crop trees are to be spaced at 16 x 16 foot intervals.

Spacing is waived whenever dwarf mistletoe is encountered. Acceptable crop trees are selected by priority as follows:

Priority 1. Free from visible infection.

Priority 2. Hawksworth infection rating maximums allowed by diameter class.

d.b.h. Class (in.)	Maximum Hawksworth Infection Rating Allowed
1 - 2	0
3 - 4	1
5 - 6	2
7 +	3

Trees To Be Removed

Except for crop or leave trees as specified above, mechanically treat the following:

All surplus conifer trees more than 4 feet tall.

All hardwoods within 20 feet of a conifer crop tree.

Trees of poor form and vigor.

All porcupine damaged trees.

All lodgepole pine.

All trees with dwarf mistletoe infection according to the infection rating-diameter class table.

All trees with dwarf mistletoe trunk infection.

Miscellaneous Instructions

Trees of nearly equal height and diameter in the unit will be ranked in priority or value by species as follows: Douglas-fir, western larch and ponderosa pine.

Trees will be cut below lowest live limb and not more than 12 inches above the ground. The trees cut must be on the ground and not "hung up" or leaning against a crop tree. All trees must be cut completely free of stump.

If snow depth exceeds 12 inches, trees will be cut below the lowest live limb and not more than 18 inches above the ground.

All damage to fences resulting from operations on this contract will be repaired immediately. All trees adjacent to fence shall be felled away from fence and all slash falling on fence shall be removed.

CONCLUSION

Dwarf mistletoe control is a proven forest management activity. The parasite need not be a problem to future forests. Training is uncomplicated and treatment is no more costly than any other activity. Contact your state or federal pest specialists for further training. Training is available for private landowners and industrial, state or federal foresters alike.

LITERATURE CITED

Russell, K. W.
1976. Operational aspects of disease control: Dwarf mistletoe. Proc. Hemlock Symposium., University of Washington, Union, Wash.

Russell, K. W., B. Howard; L. C. Weir; D. W. Johnson, and E. E. Nelson.
1975. Forest Disease Priorities in the Pacific Northwest. Special Bulletin. Pacific Northwest Forest Pest Action Council. Portland, Oreg., 15 p.

Shigo, A. L.
1976. Rx for wounded trees. Slide-tape with written text. USDA Forest Serv. Northeastern Forest Experiment Station. Upper Darby, Pa.

BIOLOGICAL AND CHEMICAL CONTROL OF DWARF MISTLETOE[1/]

Donald M. Knutson[2/]

Abstract: Biological and chemical control agents for control of dwarf mistletoe could likely be developed if we elected to develop them. Current attitudes, however, marshal against adequate study of such widespread and virulent fungal parasites as *Cylindrocarpon gillii* and *Colletotrichum gloeosporioides*.

Key words: *Wallrothiella arceuthobii*, *Colletotrichum gloeosporioides*, *Cylindrocarpon gillii*, dwarf mistletoe, biological control, chemical control.

INTRODUCTION

Forest managers and forest pathologists have long discussed the idea of controlling the dwarf mistletoes with living organisms and with chemicals that can be applied to infected trees and which selectively kill the dwarf mistletoe. After many years, however, we do not have effective chemical poisons nor have we harnessed natural enemies--such as fungi or insects--to use in those situations when silvicultural control isn't effective or appropriate. Why is this so? Is it because dwarf mistletoe has no natural enemies? Is it because these organisms can't be manipulated to our advantage? Is it because the vast North American chemical industry can't develop a selective mistletoe poison?

I would now like to examine biological and chemical control of dwarf mistletoe in more detail. I hope to convince you that the current absence of chemical and biological control agents is more the result of our attitudes than the lack of appropriate organisms or chemicals.

The basic attitude has been that forests are low-value crops and that we cannot afford special treatments, such as flying over an area and spraying spores. Since we can't afford to use them, why bother developing them? We are better off using our talents to refine normal management practices such as harvesting and thinning as a means of disease reduction. This attitude still prevails, effectively preventing the development of alternative control systems. And, since we have no alternative control schemes, of course there is no way to reduce the cost of these systems. Thus they can never be economically feasible. Neither are they available in situations where cost is not a primary consideration (parks, campgrounds). Another basic attitude on biological control is that if it really worked, dwarf mistletoe wouldn't be a problem, although many report that insects and fungal parasites of mistletoe can be locally damaging. These are the basic attitudes that keep impractical ideas from becoming practical ones.

BIOLOGICAL CONTROL

Let's talk about biological control first. Like other indigenous plants, the dwarf mistletoes have a number of organisms that do them damage--most are fungi and insects. Some are casual parasites, but many appear to have no other host.

It is probably safe to say that more than half of them are yet to be described. Someday, perhaps we will be able to knowledgeably discuss virus and mycoplasma parasites of the dwarf mistletoes.

The first dwarf mistletoe parasite was reported from New York State (Peck 1875). This was a fungus, *Wallrothiella arceuthobii* (Peck) Sacc. This ascomycete has since been reported throughout much of Canada, the Western United States and Northern Mexico.

[1/] Presented at Symposium on Dwarf Mistletoe Control Through Forest Management, Berkeley, Calif. April 11-13, 1978.

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It parasitizes female fruits of the spring flowering dwarf mistletoes--those on Douglas-fir and lodgepole pine in the West and jack pine and black spruce in the East.

Early forest pathologists were basically mycologists with a strong conviction that we cannot manipulate plant systems unless we understand them well. Thus they concentrated their efforts on the biology and classification of organisms. They were, however, very aware of the potential value of manipulating these organisms for human benefits.

In 1915, when speaking of *Wallrothiella* in the Idaho-Montana forest region, James Weir said, "It is found to be so abundant as to have some economic significance." Eleanor Dowding said much the same about this fungus on lodgepole pine mistletoe in Alberta in 1929; "...Its presence is probably of considerable importance in limiting the spread of *Arceuthobium*."

They went on to do some very good work on the biology and epidemiology of this fungus, but no attempts were made to use the fungus for biological control.

Lake Gill, another leader in the field of forest pathology, discovered (in 1932) a white fungus attacking dwarf mistletoe aerial shoots. In his 1935 publication he said it was "apparently responsible for the premature death of large numbers of [mistletoe] shoots in that area."

This fungus, now called *Cylindrocarpon gillii* (Ellis) J. A. Muir, was found by Gill on the dwarf mistletoes of western hemlock, true fir, western spruce and Mexican white pine, *Pinus strobiformis* (Gill 1935). The list of dwarf mistletoes parasitized by this fungus was expanded by Ellis (1939, 1946) to include those of Douglas-fir, piñon pine, ponderosa pine, sugar pine, limber pine and Digger pine. Later Gill (1952) reported this fungus on lodgepole pine dwarf mistletoe from Montana where the dwarf mistletoe "suffered heavy mortality." Wicker and Shaw (1968) added western larch dwarf mistletoe to the list.

The fungus has been reported from the States of Arizona, California, Montana, New Mexico, Oregon, Utah, Washington, Wyoming, and from the provinces of British Columbia, Alberta, and Saskatchewan (Kuijt 1960-61). A recent paper details the distribution of *Wallrothiella* along with *Cylindrocarpon* and *Colletotrichum*, the three major fungal parasites of the dwarf mistletoes (Hawksworth et al. 1977).

Certainly a fungus attacking so many dwarf mistletoes, often severely, over such a vast region deserves our professional attention. So let's focus on this fungus as our object-organism, follow it through the years since it was described, and see why it's still in the scientific journals instead of in the land manager's tool kit.

After noting the severity of the fungus and after sketching in the general geographic range, Ellis took the correct next step: he did a comprehensive study of the biology of this fungus (Ellis 1946), making the following main points:

1. It is found on dwarf mistletoe on 29 tree species.
2. Female plants are more frequently infected than are male plants.
3. Both immature and mature dwarf mistletoe plants are attacked.
4. It is a cool weather disease, growing slowly at 5°C, best at 17°C, and not at all at 22°C.
5. Of some 1,100 inoculated dwarf mistletoe shoots, 27 percent (range 0-90 percent) became infected. Most tests were on Douglas-fir dwarf mistletoe, but he also inoculated dwarf mistletoes on several pines in the Southwest.

He concluded by saying, "It is quite evident that *Septogloeum gillii* (now *Cylindrocarpon*) is responsible for considerable control of dwarf mistletoe under natural conditions, but further studies will be necessary to determine whether or not its introduction into new areas for purposes of biological control would be practical."

Thirteen years elapsed until Mielke (1959) published results of a study he did on establishing *Cylindrocarpon* in new areas. It didn't work well, but for understandable reasons.

Mielke collected spores on the Kaibab plateau in July from infected piñon pine and did his experiments 2 weeks later on the Cache National Forest in northern Utah and the Targhee National Forest in eastern Idaho, inoculating infected lodgepole pine. He did establish the fungus in 42 of 50 inoculated trees. It maintained its presence for 3 years and then died out. We have learned that moving plants too far from their place of origin often yields questionable and erratic results. Also, using spores from piñon pine mistletoe and inoculating lodgepole pine dwarf mistletoe is somewhat chancey. In culture dishes, *Cylindrocarpon's* growth is distinct enough so that we can tell the dwarf mistletoe host by the characteristics of the fungus colony. I would expect some host specificity in the forest also. In any case, it is exactly at this point in the drama that pathologists should become interested in asking--and answering--some sound pathology questions.

- What is the host specificity and pathogenicity of these isolates?
- Are spores not being produced?
- Are the spores not germinating?
- Is the dew-period too short, or temperatures too cold for the germ tube to grow and penetrate?

These, and other questions, would help establish the factors limiting the success of the organisms. Conversely, what characterized areas where this fungus is causing severe infection?

Both Gill (1952) and Mielke (1959) suggest that wet weather promotes growth and spread of *Cylindrocarpon*; however, the optimum dew-period, moisture drop size, etc. have not been established. Wet weather alone is not sufficient to cause epidemic levels of *Cylindrocarpon*. Marys Peak in the Oregon Coast forest is very wet for a large portion of the year, yet *Cylindrocarpon* is not found on every hemlock dwarf mistletoe plant. It is possible that insufficient moisture occurs at the time the temperature is warm enough for maximum spore production. Again, this is easy to determine. The Marys Peak hemlock dwarf mistletoe infestation is not a vigorous epidemic. *Cylindrocarpon* and a resin disease are both contributing to the debilitation of the mistletoe. There are probably other undiscovered influences.

A third very important fungal parasite of the dwarf mistletoes is *Colletotrichum gloeosporioides* Penz. This was first reported by Parmeter et al. (1959) from California. Current known range includes all Western States except Nevada and Wyoming (Hawksworth et al. 1977). It has been studied in the lab and in the forest and possesses characteristics that make it a promising biological control agent. Spores are easily produced, and these germinate over a wide range of temperatures. Disease development is rapid (2-3 weeks) and the damage severe (Parmeter et al. 1959).

These three fungi are well respected, but currently unemployed. I hope current interest in biological control (Baker and Cook 1974) coupled with the development of techniques for determining how safe these organisms are (Wapshere 1974) will help make biological control more attractive in forest management.

CHEMICAL CONTROL

Of 95 references in the mistletoe FAMULUS[3/] reference file on chemical control, 28 mention dwarf mistletoe. Of these 28, 14 are anonymous references to interim reports, annual summaries of activities, and other non-technical outlets. There has been a strong interest in chemicals by persons concerned with the dwarf mistletoe problem who felt the need for alternatives to silvicultural control. This interest and concern began to surface in the reports of spraying results that first appeared in the early 1950's and continued at the rate of about one report per year for a decade. Most compounds tested were commercially available herbicides.

Results were largely negative and persistently erratic, prompting Harold Offord (1960) to state, "Of the many compounds and formulations so far tested on dwarf mistletoes, none has looked very exciting." The following year Shea (1961) said,"We urgently need development of promising chemicals that will permit selective absorption and translocation in the parasite and host plant."

Clarence Quick (1964) published a summary of 246 tests on 2,516 trees of Jeffrey, ponderosa and sugar pine in California. He optimistically concluded his report saying, "When all established tests have matured, it is believed that a safe, reasonably effective direct chemical control of dwarf mistletoe on pines can be defined." It has been 14 years since Quick's report; and many attempts later, we must conclude that the development of an effective, selective chemical poison for dwarf mistletoe is still in the early stages. Like Edison and his light bulb, we know a lot of things that don't work! And there are some slim leads. Greenham and Leonard (1965) discovered an amino acid, hydroxyproline, in true fir dwarf mistletoe, but not in the host tree. They propose that analogs of this amino acid might be used for mistletoe control: "How toxic analogs would be to plants containing free hydroxyproline is not known at present.

[3/] On file at Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

So many factors are involved in selective toxicity that the effectiveness of a potential selective herbicide can be gauged only by direct experimentation. The above investigation has given leads worthy of further attention." These leads have not been followed up.

Leonard and Hull have also published several comprehensive papers on translocation, nutrition, and photosynthesis of dwarf mistletoes (Leonard and Hull 1965; Hull and Leonard 1964). Among other important papers, one is on translocation (Rediske and Shea 1961) and two on water relations of dwarf mistletoe (Mark and Reid 1971; Fisher 1975). Work at Portland State University, Oregon, on dwarf mistletoe photosynthesis and respiration (Miller and Tocher 1975; Gustafson and Tocher, personal communication), dwarf mistletoe hormones (Paquet and Tinnin, personal communication), and aspects of dwarf mistletoe stomates and phloem tissue (Calvin, personal communication) is helping to provide ground work for understanding some of the main aspects of the problem of chemical control of dwarf mistletoe, namely:

1. Moving the poison throughout the tree.
2. Moving the poison to the infections.
3. Moving a poison from the tree tissue into the mistletoe tissue.

Of these, number 3 is the most important. If efforts here are successful, aspects 1 and 2 will be relatively easy.

In summary, biological and chemical control agents are not now operational options available to managers. Nor will they be in the future unless we convince ourselves that we truly need control methods other than the chain saw.

LITERATURE CITED

Baker, K. F. and R. J. Cook.
1974. Biological control of plant pathogens. W. H. Freeman and Co., San Francisco. 433 p.

Dowding, E. S.
1929. The vegetation of Alberta. III. The Sandhill areas of central Alberta with particular reference to the ecology of *Arceuthobium americanum* Nutt. J. Ecol. 17:82-105.

Ellis, D. E.
1939. A fungus disease of *Arceuthobium*. Phytopath. 29:995-996.

Ellis, D. E.
1946. Anthracnose of dwarf mistletoe caused by a new species of *Septogloeum*. J. Elisha Mitchell Society 62:25-50.

Fisher, J. T.
1975. Water relations of dwarf mistletoe on pine. Ph.D. Thesis, Colorado State Univ., Fort Collins, Colo.

Gill, L. S.
1935. *Arceuthobium* in the United States. Trans. Conn. Acad. Arts and Sciences 32: 111-245.

Gill, L. S.
1952. A new host for *Septogloeum gillii*. Plant Dis. Rep. 36(7):300.

Greenham, C. G. and O. A. Leonard.
1965. The amino acids of some mistletoes and their hosts. Amer. J. Bot. 52(1): 41-47.

Hawksworth, F. G., E. F. Wicker, and R. F. Scharpf.
1977. Fungal parasites of dwarf mistletoe. USDA, For. Serv. Gen. Tech. Rep. RM-36, 14 p., illus. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Hull, R. J. and O. A. Leonard.
1964. Physiological aspects of parasitism in mistletoes (*Arceuthobium* and *Phoradendron*). I. The carbohydrate nutrition of mistletoe. II. The photosynthetic capacity of mistletoe. Plant Physiol. 39:996-1017.

Kuijt, J.
1960-61. Distribution of dwarf mistletoes and their fungus hyperparasites in western Canada. *From* Nat. Museum of Canada, Bull. No. 186, Contrib. to Bot. p. 134-148.

Leonard, O. E. and R. J. Hull.
1965. Translocation relationships in and between mistletoes and their hosts. Hilgardia 37(4):115-153.

Mark, W. R. and C. P. P. Reid.
1971. Lodgepole pine dwarf mistletoe water potentials. For. Sci. 17:470-471.

Mielke, J. L.
1959. Infection experiments with *Septogloeum gillii*, a fungus parasitic on dwarf mistletoe. J. For. 57:925-926.

Miller, R. J. and R. D. Tocher.
1975. Photosynthesis and respiration of *Arceuthobium tsugense* (Loranthaceae). Amer. J. Bot. 62(7):765-769.

Offord, H. R.
1960. New approaches to forest disease control by chemicals. Fifth World For. Congr. Proc. 2:882-887.

Parmeter, J. R., J. R. Hood, and R. F. Scharpf.
1959. *Colletotrichum* blight of dwarf mistletoe. Phytopath. 49:812-815.

Peck, C. H.
1875. Report of the botanist. New York State Museum of Natural History, Ann. Rep. 27:111.

Quick, C. R.
1964. Experimental herbicidal control of dwarf mistletoe on some California conifers. USDA, For. Serv. Res. Note PSW-47. 9 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Rediske, J. H. and K. R. Shea.
1961. The production and translocation of photosynthate in dwarf mistletoe and lodgepole pine. Amer. J. Bot. 48(6): 447-452.

Shea, K. R.
1961. Dwarf mistletoe of ponderosa pine: present status and future needs. *In* Recent Advances in Bot. p. 1541-1544.

Wapshere, A. J.
1974. A strategy for evaluating the safety of organisms for biological weed control. Ann. Appl. Biol. 77: 201-211.

Weir, J. R.
1915. *Wallrothiella arceuthobii*. J. Agric. Res. 4(4):369-378.

Wicker, E. F. and C. G. Shaw.
1968. Fungal parasites from dwarf mistletoes. Mycologia 60(2):372-383.

Pest Damage and Integrated Control

INTEGRATING DWARF MISTLETOE

CONTROL WITH FOREST MANAGEMENT[1]

William E. Waters[2]

Abstract: A broader, more comprehensive concept of forest pest management is needed to make it a really integral part of forest resource management. A generalized model structure of a forest pest management system is presented, and the major components are discussed briefly. Predictive models are the primary mechanism of information flow to decision and action in the system. General considerations affecting the kind and number of these models are discussed, with particular reference to the dwarf mistletoes. The whole-system approach to dwarf mistletoe management is urged.

The focus of this symposium is on dwarf mistletoe *control*. Each of the symposium sections -- including this, the last -- has the word *control* in its title. The various papers presented thus far have covered the relevant biology of the mistletoes, their ecological relations with host trees and stands, their effects on growth and yield and some damage statistics for different host types and geographic regions, and various control techniques for prevention or amelioration of the damage to be expected. The term *management* has crept in at times, and this has been expanded to *integrated management* in several contexts. The nature of dwarf mistletoe effects on forests has made the use of these terms fairly common, in fact. But what do we really mean by integrated pest management, or integrated management of dwarf mistletoes?

The concept of forest pest management -- the notion that destructive diseases (and insects) are an integral part of forest ecosystems, that they have both ecological and economic impacts on those ecosystems and the resource values involved, and that somehow their effects have to be kept at tolerable levels in ways compatible with forest management objectives and practices -- is not new (Meinecke 1916; Hopkins 1909). However, the concept has little reality in practice. The attitude of forest managers and administrators generally has been to play the game of "wait and see," followed by seat-of-the-pants decisions on action when a pest becomes obvious, intrusive, or intolerable. This attitude has affected research priorities, time schedules, and methodology accordingly.

If we better understand the full meaning of integrated pest management -- its space-time dimensions, the complexities and interactions of its ecological and economic components and the social and political factors that inevitably have a part in planning and decision-making -- perhaps we can better set our sights on the research now needed and improve the odds of getting forest resource managers and administrators to put our collective knowledge and technology to work. Our real goal should be a forest protection system that incorporates dwarf mistletoe control -- and control or regulation of all other destructive agents that may be involved -- into the total resource management process on a long-term, continuing basis.

Let us look at the basic components of a forest pest management system. Figure 1 shows a generalized model structure of such a system (Waters and Cowling 1976). There are four basic components (enclosed by the dotted lines) (1) the population dynamics and epidemiology of the insects and diseases involved, (2) the dynamics of forest stand development, (3) the socioeconomic impacts of pest-caused damage on resource values, and (4) the treatment strategies. Each component is a complex subsystem in itself; each requires detailed analysis and

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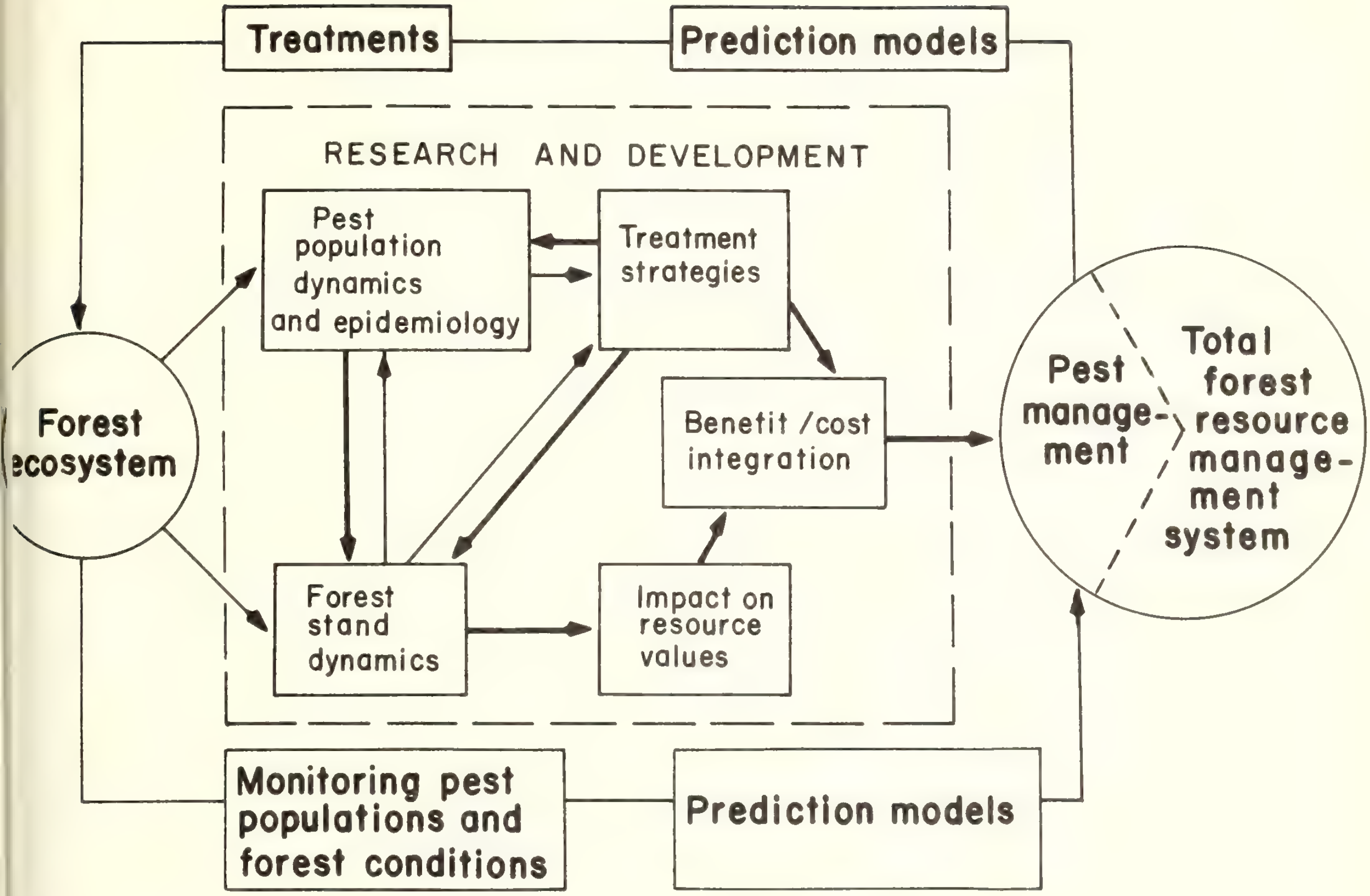

Treatments
Prediction models
RESEARCH AND DEVELOPMENT
Pest population dynamics and epidemiology
Treatment strategies
Benefit /cost integration
Forest ecosystem
Forest stand dynamics
Impact on resource values
Pest manage-ment
Total forest resource manage-ment system
Monitoring pest populations and forest conditions
Prediction models

Figure 1--Generalized model structure of a forest pest management system.

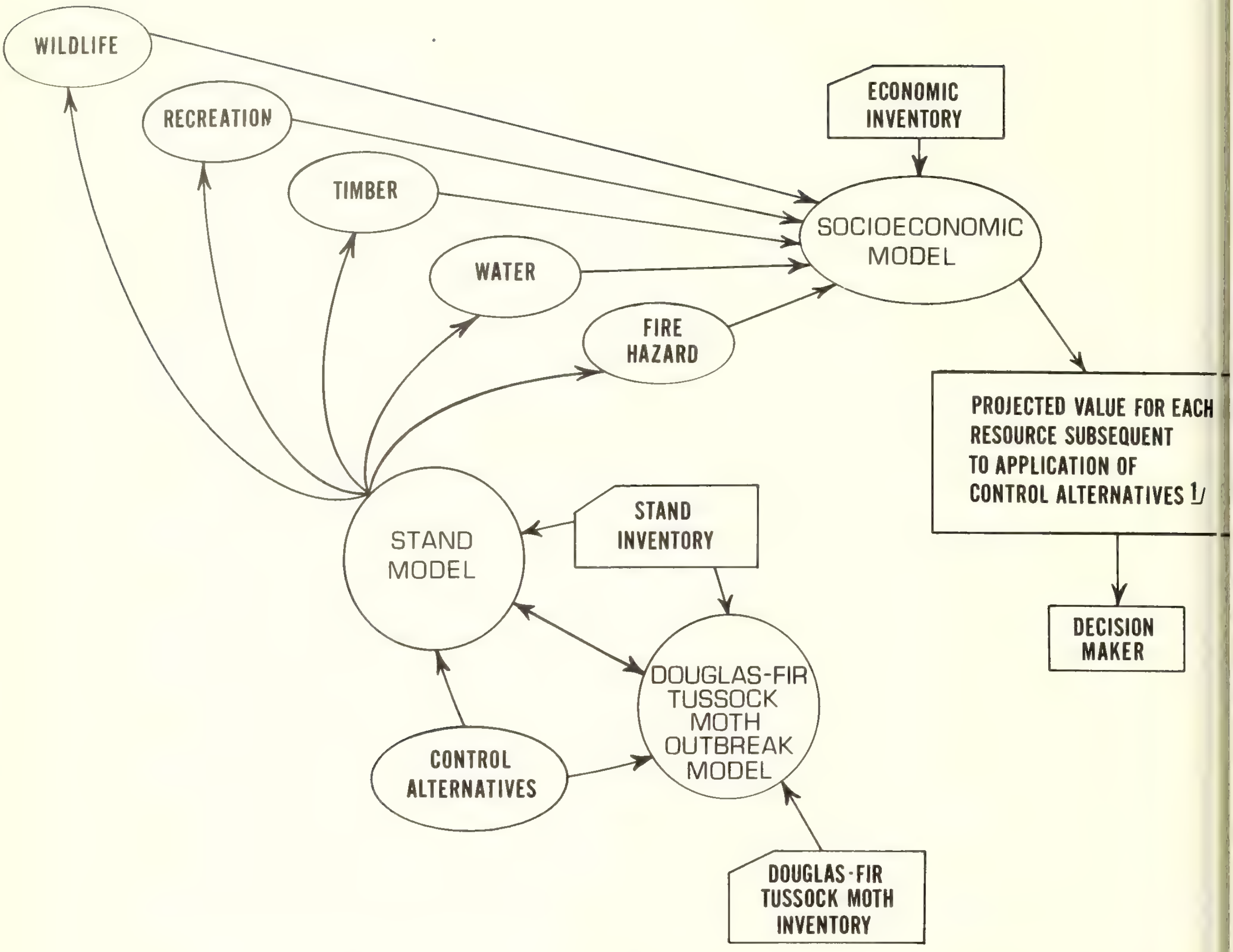
understanding to provide the particular predictive models called for in the operational system. The heavier arrows show the primary linkages, or information flows, in the planning-decision process. The focal point of the system is the benefit/cost integration, whereby the benefits (values saved or gained) and the costs of alternative treatments or actions are assessed.

Figure 2 shows the same general model in a different configuration (Campbell and McFadden 1977). This emphasizes the different resource values and management objectives that may be at stake.

Predictive models are the primary mechanism of information flow to decision and action in an operational system (Waters and Ewing 1975). We must have the capability to anticipate the occurrence, abundance, and trends in pest populations. We must be able to estimate their potential effects on stand growth and yield and other stand parameters of concern, and to put these in terms of the values that will be affected. And we have to be able to specify in advance the expected outcomes of different treatments or management activities, including no action, not just in terms of the effects on the pest(s) but in terms of values lost, saved, or gained as well. This look-ahead feature is a major distinction between pest management and pest control.

The kind and number of predictive models in the system depend in part, of course, on the pest or pest complex involved. But some general considerations apply in all cases, including the management of dwarf mistletoe. These are:

(1) The time-span of the tree "crop"--cutting cycles and rotation ages will differ with tree species, location, and management objectives. This is a factor certainly with


WILDLIFE
RECREATION
TIMBER
WATER
FIRE HAZARD
ECONOMIC INVENTORY
SOCIOECONOMIC MODEL
PROJECTED VALUE FOR EACH RESOURCE SUBSEQUENT TO APPLICATION OF CONTROL ALTERNATIVES 1/
DECISION MAKER
STAND MODEL
STAND INVENTORY
DOUGLAS-FIR TUSSOCK MOTH OUTBREAK MODEL
CONTROL ALTERNATIVES
DOUGLAS-FIR TUSSOCK MOTH INVENTORY

1/ Projected values subsequent to exercising the "no control" alternative will provide a base line for estimating benefit/cost rati

Figure 2--Information inputs, flows, and outputs in the Douglas-fir tussock moth research and development program (from Campbell and McFadden 1977).

dwarf mistletoes, considering the wide range of situations in which they are involved.

(2) The phenology of the tree(s) relative to the life cycle and activity of the pest--the extent to which critical stages of the pest, such as establishment and infection, are dependent on being synchronized with host plant development. This may not be very important with the dwarf mistletoes.

(3) The annual number of generations and seasonal abundance of the pest--whether the pest has one, two, or more generations or cohorts a year; the

rate of increase in each cohort; and the potential for increase in successive years. As I understand it, there is some variation in this factor among the dwarf mistletoes over the range of hosts and conditions in which they occur.

(4) The manner of spread and dispersal capability of the pest--whether spread or dispersal is active or passive, short- or long-range, random or contagious (dependent on direct contact of infected hosts), regular or irregular in frequency, etc. This factor, along with host conditions, determines the pattern and rate of spread of infection or infestation in stands or areas. It certainly is an important consideration with the dwarf mistletoes.

(5) The kind and rate of damage inflicted --whether the effect on stands is qualitative (*i.e.* cosmetic) or quantitative; whether outright tree mortality, growth loss, or some combination of these is involved; the age-size distribution of trees affected; the relation between rate of damage and loss and pest numbers or infection sources; and the shifting interplay between measured damage and loss and management objectives, expressed as thresholds for action. All of these factors are involved in the prediction of damage and loss due to dwarf mistletoes in particular situations.

(6) The kind and frequency of treatments --whether biological, cultural, chemical, or an integrated mix of methods are to be employed, and the time sequence in which they will be applied (within a given year and over successive years). For every pest or pest complex, including dwarf mistletoes, every alternative will have a different expectation of outcomes in terms of protection afforded and cost.

(7) The scope and objectives of the pest management program--the space-time frame of the program; whether prevention, suppression, long-term regulation, or some combination of these is intended. This determines the dimensionality of the entire set of predictive models in the system.

(8) Silvicultural considerations and management objectives--whether the stands are to be managed under an even-aged, 2-storied, group selection, individual tree selection, or some other silvicultural system, and the frequency of operations related to these; the products or product mix and other uses and values intended. These considerations establish constraints on all components of the system -- on the stand dynamics and impact models particularly.

This all sounds complicated -- and it can be. We don't, in fact, have all the pieces for any major pest. But some simplifications -- in methodology, not in the overall concept -- can be made as a start. Where do we stand with the dwarf mistletoes, for example?

Firstly, all of the current knowledge of dwarf mistletoe biology and epidemiology -- and this is well summed up at this Symposium -- can be wrapped up in two models which express (1) the conditional probabilities of dwarf mistletoe occurring in individual stands or management units based on tree and stand characteristics, proximity of infection sources, and other quantifiable variables, and (2) the rate of increase in mistletoe damage, including mortality, by tree species, age class, a spatial index, infection level, and, again, other quantifiable variables determining predictive accuracy and precision. An approach to developing such models for disease management, utilizing a logical simulation of the processes of disease establishment and buildup, has been described by Waggoner (1976). Stage (1973, 1975) has provided a computerized, algorithmic basis for putting expectations of pest incidence and damage into projections of stand growth and development for forest management planning. A more detailed exposition of the rationale and mathematics of integrating forest pest dynamics and stand dynamics into the management decision-making process has been given by Stage and Long (1976). The incorporation of earlier whole-stand models of lodgepole pine and ponderosa pine infested by dwarf mistletoe (Myers et al. 1971, Myers et al. 1976) into a new computer program by Edminster (1978) covering a wider range of stand conditions is a significant step in developing the practicable kind of input needed on mistletoe incidence and effects over time. These approaches, and the models and computerized procedures to utilize them, combine in effect the information contained in the pest population and stand dynamics boxes of the general model.

The assessment and projection of potential impacts of destructive insects and diseases -- their cumulative net effects on the productivity, usefulness, and value of a tree species or forest type with respect to different resource uses and management objectives -- is an area which forest pathologists (and entomologists) have usually avoided. Properly so. The ecological, economic, and social complications of this aspect of pest management were dissected and reconstructed at a U.S. Forest Service-sponsored work conference at Marana Park, Arizona, in 1972. The report of that conference did much to clarify terms and to distinguish explicitly between the measurement and prediction of changes in stand parameters brought about by the activities of diseases and insects and the effects of those changes in terms of values affected (U.S. Forest Service 1972). The ecological and economic complications, research and applied approaches to impact evaluation, and data requirements in an operational system, have been more fully summarized by Waters (1976). I believe we now have a clear communication link with forest economists and forest managers and, importantly, a better basis for mutual understanding of where and how value judgments should be entered into the general model for planning and decision. Specifically, in the case of dwarf mistletoes, it would seem that the current values and related economic parameters of managed stands of most, if not all, of the host tree species are well enough known and sufficiently amenable to simulation for a reasonable number of years ahead that this component of the dwarf mistletoe management model could now be filled in.

Similarly, from research and management experience, it should be possible to develop reasonably accurate estimates of the costs and effectiveness of silvicultural treatments, or management practices, for prevention or amelioration of dwarf mistletoe damage for a realistic spectrum of infestation conditions.

With regard to benefit/cost integration -- the place where the whole process comes together -- new applications of simulation and optimization techniques have been developed specifically for pest management (Shoemaker 1976). Even more relevant methods are being developed in the "big bug" programs -- the USDA Combined Forest Pest Research and Development Program aimed at the Douglas-fir tussock moth, southern pine beetle, and gypsy moth (Ketcham and Shea 1977).

So long as some information essential to the whole-system approach to managing a particular pest is lacking, with attendant uncertainties, probably the best procedure for short-term decisions is decision-tree analysis. With this approach, the available information on pest-forest interactions compacted into predictive models, and cost estimates for alternative actions, are combined with subjective probabilities to form a discrete set of pathways to an array of outcomes, from which a choice is made based on some utilitarian criterion such as maximum benefit per unit cost (Valentine et al. 1976). The limitation to this approach is that the risks of a bad choice may be quite high depending on the caliber of the data and the assumptions used in constructing the decision-tree. A more serious shortcoming is that it cannot be incorporated easily into a forest management model. Numerous decision-trees may be needed for a given pest or pest complex, and the variables and criteria used may be more or less unique for the situation involved. Regardless, this approach has a strong appeal as an interim procedure, at least, and it undoubtedly would be useful for many dwarf mistletoe situations.

In the longer view, there is good reason to set our sights on a complete management system for the dwarf mistletoes -- and, ultimately, on total protection systems against all destructive agents affecting the coniferous forests of the Western United States. The long-range program goals of the Renewable Resources Planning Act of 1974 and the mandate of the National Forest Management Act of 1976 both give protection of our forest resources high priority. The environmental benefits to be derived also support this view. There is an opportunity for the dwarf mistletoes to serve as the prototype for forest disease management on the scale envisioned here. I, for one, believe we should get at it.

LITERATURE CITED

Campbell, R.W., and M.W. McFadden.
1977. Design of a pest management research and development program. Bull. Ent. Soc. Amer. 23:216-220.

Edminster, C.B.
1978. RMYLD: Computation of yield tables for even-aged and two-storied stands. USDA Forest Serv. Res. Paper RM-199. Rocky Mt. Forest and Range Exp. Stn., Fort Collins, Colo. (In press).

Hopkins, A.D.
1909. Insect depredations in North American forests and practical methods of prevention and control. USDA Bur. Entomol. Bull. 58, Part V. 101 p.

Ketcham, D.E., and K.R. Shea.
1977. USDA combined forest pest research and development program. J. Forestry, 75: 404-407.

Meinecke, E.P.
1916. Forest pathology in forest regulation. USDA Bur. Plant Industry Bull. 275. 62 p.

Myers, C.A., C.B. Edminster, and F.G. Hawksworth.
1976. SWYLD2: Yield tables for even-aged and two-storied stands of southwestern ponderosa pine, including effects of dwarf mistletoe. USDA Forest Serv. Res. Paper RM-163. Rocky Mt. Forest and Range Exp. Stn., Fort Collins, Colo. 25 p.

Myers, C.A., F.G. Hawksworth, and J.L. Stewart.
1971. Simulating yields in managed, dwarf mistletoe-infested lodgepole pine stands. USDA Forest Serv. Res. Paper RM-72. Rocky Mt. Forest and Range Exp. Stn., Fort Collins, Colo. 15 p.

Shoemaker, C.
1976. Management models for integrated pest control -- mathematical structure and solution. *In* Modeling for Pest Management: Concepts, Techniques, and Applications (R.L. Tummala, D.L. Haynes, and B.A. Croft, eds.), pp. 32-39. Michigan State University, East Lansing.

Stage, A.R.
1973. Prognosis model for stand development. USDA Forest Serv. Res. Paper INT-137. Intermountain Forest and Range Exp. Stn., Ogden, Utah. 32 p.

Stage, A.R.
1975. Stand prognosis in the presence of pests -- developing the expectations. *In* Management of Lodgepole Pine Ecosystems (D.M. Baumgartner, ed.), pp. 233-245. Washington State Univ. Coop. Extension Service, Pullman, Wash.

Stage, A.R., and G.E. Long.
1976. Forest stand dynamics as a basis for integrated management of forest pests. *In* The Bases for Integrated Pest Management, Proceedings of Group 6, XVIth IUFRO World Congress, Oslo, Norway, June 1976 (D.L. Kibbee, ed.), p. 19-28. University of Idaho, Moscow, Idaho.

U.S. Forest Service.
1972. Report of the Workshop on Impacts of Insects and Diseases on Uses, Values, and Productivity of Forest Resources. USDA Forest Service, Washington, D.C. 64 p. (Processed).

Valentine, H.T., C.M. Newton, and R.L. Talerico.
1976. Compatible systems and decision models for pest management. Environ. Entomol. 5:891-900.

Waggoner, P.E.
1976. Predictive modeling in disease management. *In* Modeling for Pest Management: Concepts, Techniques, and Applications (R.L. Tummala, D.L. Haynes, and B.A. Croft, eds.), pp. 176-186. Michigan State University, East Lansing.

Waters, W.E.
1977. Evaluation of insect impacts on forest productivity and values. *In* The Bases for Integrated Pest Management, Proceedings of Group 6, XVIth IUFRO World Congress, Oslo, Norway, June 1976 (D.L. Kibbee, ed.), pp. 15-18. University of Idaho, Moscow, Idaho.

Waters, W.E., and E.B. Cowling.
1976. Integrated forest pest management: a silvicultural necessity. *In* Integrated Pest Management (J.L. Apple and R.F. Smith, eds.), pp. 149-177. Plenum Press, New York.

Waters, W.E., and B. Ewing.
1975. Development and role of predictive modeling in pest management systems -- insects. *In* Modeling for Pest Management: Concepts, Techniques, and Applications (R.L. Tummala, D.L. Haynes, and B.A. Croft, eds.), pp. 19-27. Michigan State University, East Lansing.

THE PEST DAMAGE INVENTORY IN CALIFORNIA[1]

James W. Byler[2]

Abstract: The Pest Damage Inventory (PDI) is a survey procedure used by the U.S. Forest Service's California Region for measuring pest-caused damage over large forested areas. Similar procedures are followed in each survey, but photo and ground sampling techniques may differ. Six PDI surveys have been completed to date. Results show that dwarf mistletoe is a major contributor to tree mortality. The parasite is but one major class of tree pests, and pest management systems must integrate treatments for the entire pest complex. Pest management prescriptions should be integrated with stand management prescriptions.

INTRODUCTION

The Pest Damage Inventory (PDI) is a survey system that provides estimates of damage caused by forest pests. The PDI measures the damage from all pests in one survey, rather than makes multiple surveys for the various insects and diseases. The total damage is partitioned among pathogens, insects, abiotic factors, and complexes of these agents.

The PDI provides information for integrated control in the broad sense. Pest management strategies for each of the major pests and pest complexes are integrated with silvicultural treatments to form stand prescriptions aimed at achieving the desired stand structure, composition, and productivity. The emphasis is on forest management for insect and disease prevention, rather than on remedial insect or disease control.

This paper describes methods and selected results from inventories made in several National Forests in California during the past 5 years. It centers on dwarf mistletoes as causes of mortality and growth loss. But the results and discussion are not confined to dwarf mistletoes. My approach will be to put dwarf mistletoes in perspective as causes of tree mortality, to suggest a method for measuring growth loss and dwarf mistletoe incidence, and to describe an approach for integrating dwarf mistletoe treatments into silvicultural prescriptions that is being used in the Forest Service's California Region.

MORTALITY SURVEYS

Pest Damage Inventory methods are used for measuring tree mortality over large forested areas. The estimates of loss obtained from the surveys are used mainly for two purposes.

1) Biological evaluations: The California Region's Forest Insect and Disease Management Staff uses the PDI for biological evaluation surveys where the areas of concern are large and where tree mortality is the primary concern. The Staff evaluates specific insect and/or disease problems in response to requests from the National Forest Supervisors and other land managers. These evaluations contain estimates of the level of damage and cause of the damage that are obtained from surveys.

2) Administrative uses: Estimates of the level of tree mortality and the cause of that mortality are also used by administrators in setting action and research priorities. PDI estimates for the 12 National Forests in northern California are being used for such purposes.

To date, six tree mortality surveys have been completed: the Moore Creek Compartment of the Stanislaus National Forest in 1972;

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eight townships on the Eldorado National Forest in 1973; the commercial forest land of the Stanislaus National Forest in 1974; the pine and mixed conifer types on the San Bernardino National Forest in 1976; Laguna Mountain on the Cleveland National Forest in 1977; and a drought survey of tree mortality on 12 National Forests in northern California in 1977.

The six surveys had three objectives in common: (1) to measure the tree mortality that occurred during a one year period; (2) to identify the insects and diseases, separately or in combination, that were responsible for that mortality; and (3) to identify the stand and site conditions that are associated with above-normal mortality.

Loss estimates from four surveys are given as examples in this report: the Eldorado National Forest area, the San Bernardino National Forest, Laguna Mountain, and the drought survey of 12 National Forests.

METHODS

Similar procedures were followed in each survey. But the surveys differed in the photo and ground sampling technique and in sampling intensity.

Photo Plot Selection

Aerial photographs were used to detect dead trees. One hundred percent photo coverage was used on the Laguna Mountain area. Random sampling was used for the remaining surveys: random photo plot placement in the commercial forest type for the drought survey, and stratified random sampling by timber type for the remainder.

Photo plots were square and covered 284 acres unless part of the area was out of the timber type or was off the forest. Plots with less than 50 acres of commercial forest type were excluded from the San Bernardino and Eldorado National Forest surveys. Plots with less than 140 acres were excluded from the drought survey sample.

Each sample plot (or the entire area in case of 100 percent coverage) was photographed at a scale of 1:8000 by using 75 percent overlap for stereo viewing. Nine-and-one-half-inch wide Ektachrome MS film (type 2448), a Zeiss RMK camera with an 8¼ inch lens, HF 3 or 4 haze filters, and an antivignetting filter were used.

Photointerpretation

The aerial photos were examined for dead tree groups by delineating photo plot boundaries on the center photograph of each triplet and viewing the plots in stereo at 4x to 8x magnification. Each tree or group of dead trees within the photo plot that appeared yellow-to-sorrel at the time of photography was encircled on the photograph. Such faded trees were considered to have died within 1 year prior to the time of photography. For each dead tree group, the photointerpreter recorded the number of dead trees, and the species and size class of each dead tree. Three size classes were used: less than 50 feet; 50 feet to 100 feet; greater than 100 feet.

Ground Survey

A stratified sample of photo-detected dead tree groups was selected for ground sampling. Trees were stratified by height class for the drought survey, and by height class and tree species for the other surveys. The selected dead-tree groups were visited on the ground to gather data used to calculate estimates of tree mortality. These data included number of trees in the group, the species and size class of each tree, and the year in which each tree died. The year of death was estimated primarily from color and condition of the foliage, and the condition of the bark.

Stand, tree, and pest data were recorded for all trees that were found to have faded within the year prior to photography. Trees were examined for pests in the following manner: crowns and upper boles were observed through binoculars, bark was removed from lower boles, and axe cuts were made at the root crown and in the uppermost roots. Pests present in each tree were rated and recorded. In addition, those pests that were considered the most important found on all trees in the mortality group were included in the pest complex for that group. Only known tree-killing pests or conditions were included in the pest complex, and these were listed only when symptoms and signs indicated that the pest had contributed to the death of the trees.

Fomes annosus was included when typical stain, decay, or conks were found on the tree or other trees in the same disease center, or when the presence of the fungus could be verified by incubating wood samples. Wood samples were collected and incubated whenever Fomes annosus was suspected but could not be confirmed by stain, typical decays, or conks.

Armillaria mellea is both a parasite and a saprophyte on conifers in California. It was included in the pest complex only when a dead oak was present on the site near enough to provide a food base (a condition under which the fungus is a virulent pathogen), or when symptoms and signs indicated that the fungus had caused root decay and killing by the time of tree death. Frequently, both *A. mellea* and *F. annosus* were present, especially on true firs. In such cases, only *F. annosus* was listed in the pest complex, although it should be recognized that the decay and killing was caused by both root pathogens.

Dwarf mistletoes were included in the pest complex when a tree was rated four or more in Hawksworth's six class system (Hawksworth and Lusher 1956). Lighter infections tended to be restricted to the lower half of the crown, and were not considered to be serious enough to be a cause of a tree's death.

Dendroctonus spp., *Scolytus ventralis*, and other insects were listed as pests when their distinctive brood galleries indicated their presence and successful attack of the tree.

The pest complex was used to calculate the proportions of trees killed by individual insects, pathogens, and pathogen/insect combinations (fig. 1-5). Tree mortality was said to be "induced" by an insect or pathogen if that insect or disease was listed in the pest complex. As it is used here, the term "induced" does not mean that a pest was the sole cause, but one of the contributors to the death of the tree.

The inventory design was multi-stage sampling with variable probabilities and stratification. Unbiased estimates of tree mortality and their standard errors were computed using methods suited to the sampling design.

RESULTS AND APPLICATION

Northern California National Forests

Three pilot tests of PDI mortality survey methods were made during years of normal mortality: the 10,000-acre Moore Creek Compartment on the Stanislaus National Forest in 1972, 87,000 acres of the Eldorado National Forest in 1973, and the entire timber-producing lands of the Stanislaus National Forest (about 1 million acres) in 1974. The tests showed the feasibility of obtaining reliable estimates of current tree mortality for large areas.

Dwarf mistletoes were implicated in the deaths of a substantial proportion of the trees in each area. Mortality estimates from the Eldorado National Forest survey area are used as an example (fig. 1). Twenty-three percent

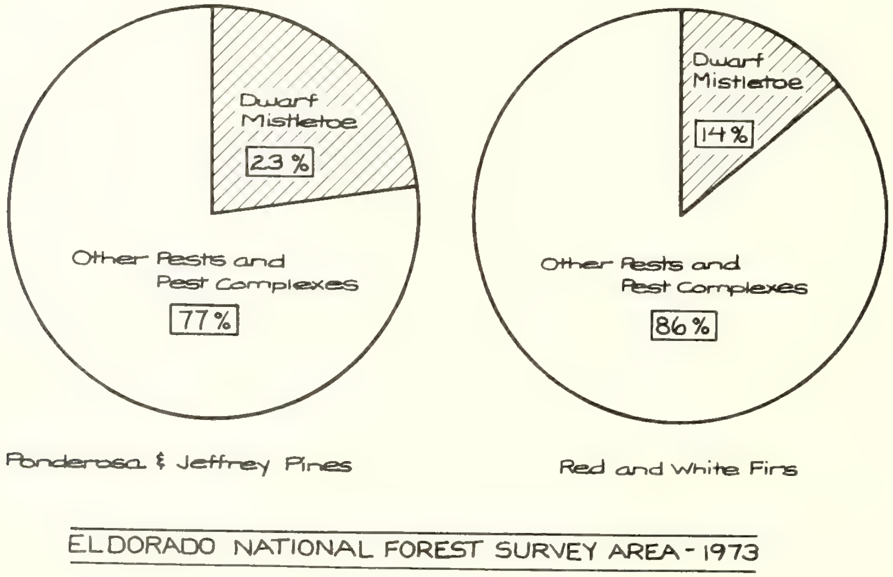

Figure 1 -- The relationship between dwarf mistletoe-induced mortality and total mortality of yellow pines and true firs in the Eldorado National Forest survey area.

of the ponderosa and Jeffrey pines and 14 percent of the red and white firs were heavily infested with dwarf mistletoe at the time of death (dwarf mistletoe ratings of 4-6). I concluded that the heavy infestation was one of the factors that brought about their death, although the exact level of dwarf mistletoe infection necessary to kill trees in the presence and absence of other pests is not known.

Nearly all of the dead pines and firs also showed evidence of successful insect attack. Brood galleries of tree-killing bark beetle species were present under the bark of the trees, and these likely played a role in killing the trees also.

The apparent association between "insect-killing" and dwarf mistletoe infestation has been recognized for some time. Miller and Keen (1960) discussed the role of pathogens, including dwarf mistletoe, in increasing pines' susceptibility to insect attack. More recent survey information from other Forest Service Regions, for example, Region 2 (Frye and Landis 1975, Johnson and others 1976), Region 3 (Parker and others 1975), and Region 4 (Parker and Stipe 1974) indicates that trees with high mistletoe ratings are more likely to be attacked by insects and killed than are uninfested ones.

The PDI was used operationally in 1977 to survey 12 northern California Forests (6.3 million acres of commercial Forest Service land) to measure the drought-associated tree mortality. The survey was designed to obtain volume loss estimates for administrative purposes. The estimated level of mortality was 4.5 ± 0.8 million trees or 1.2 ± 0.3 billion Schribner board feet for the 1 year period from May 1976 to May 1977 (0.71 trees/acre). This level was about three times the estimated normal loss.

Because of the limited ground sampling the estimates of loss by pest and pest complex have high standard errors. However, they suggest that dwarf mistletoe was associated with a sizable proportion of the mortality (fig. 2). The proportion of the recently killed pines with dwarf mistletoe ratings of 4 to 6 was especially high -- 79 percent. Again, insects infested nearly all of the trees, suggesting that they too contributed to their deaths.

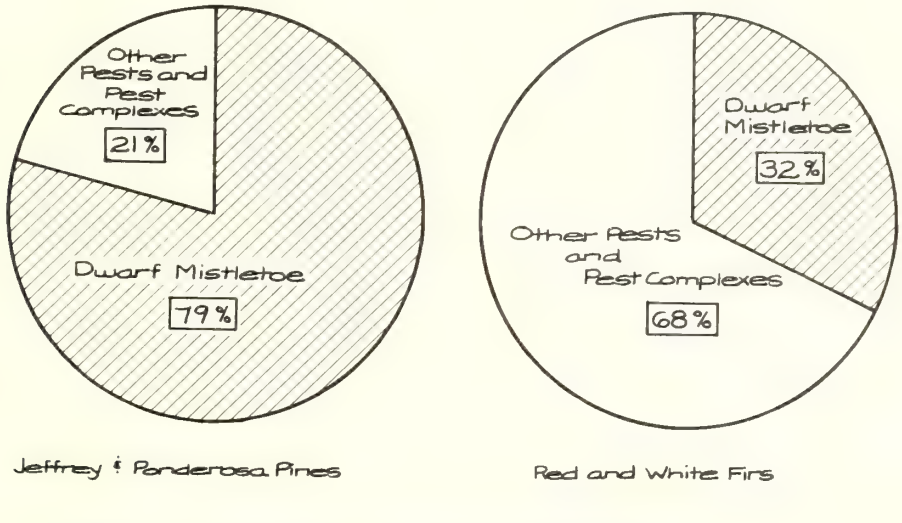

Figure 2 -- The relationship between dwarf mistletoe-induced mortality and total mortality of yellow pines and true firs in the drought survey of 12 northern California National Forest.

Root pathogens were also important in inducing tree mortality in the 12 forests. Root pathogens appeared to be more important than dwarf mistletoes in causing the death of the true firs (fig. 3), although they were associated with fewer dead pine trees than was dwarf mistletoe. Root damage and heavy crown infestations of dwarf mistletoe were both present on a sizable proportion of the recently-killed firs (fig. 3).

F. annosus was the predominant root pathogen, but signs of A. mellea and F. annosus were frequently present on the same tree. Some firs appeared to have been killed by A. mellea in the absence of F. annosus, but in those cases a dead oak or oak stump was usually present to serve as a food base for A. mellea.

Recent reports on root disease in California (Bega and others 1966, Stark and Cobb 1969, and Cobb and others 1974) and in Idaho (Partridge and Miller 1972, Miller and Partridge 1974) show that root pathogen/insect associations are common, and indicate that pathogens predispose trees to insect attack.

These northern California results indicate that dwarf mistletoes are important contributors to tree mortality. They may be especially important during periods of drought, or when stocking densities are high and the trees are under additional stress.

But perhaps more importantly, the results indicate that other pathogens and insects also contribute to tree mortality and should not be overlooked. The role of each major pest must be understood if control efforts are to be maximized. Stand treatments may and frequently should aim to reduce the levels of dwarf mistletoe in the stand. But little benefit may result unless stand treatments also prevent or reduce the damage from root pathogens and make the stand less susceptible to insect attack.

Southern California National Forests

In southern California, the pine forests on Laguna Mountain, Cleveland National Forest, were surveyed in 1977, and the pine and mixed conifer forest types on the San Bernardino National Forest are now being surveyed. The San Bernardino survey (a cooperative effort among the University of California, Berkeley; Environmental Protection Agency; and Forest Service) was begun in 1976 and is scheduled to last

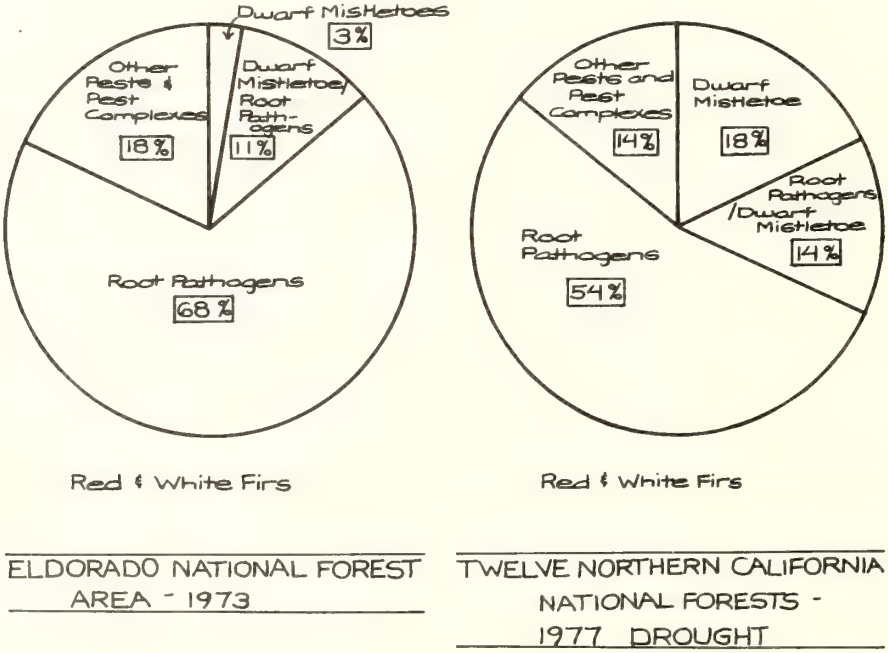

Figure 3 -- The relationship between dwarf mistletoe and root pathogen-induced mortality of true firs in the Eldorado National Forest survey area, and the drought survey of 12 northern California National Forests. Fomes annosus was the major root pathogen.

3 years.

Information from the Laguna Mountain survey and the first year of the San Bernardino survey are described here. The levels of tree mortality (0.62 trees/acre/year on Laguna Mountain and 0.07 trees/acre/year on the San Bernardino National Forest) are considered at or below normal for these areas, since rainfall was normal or greater.

Heavy dwarf mistletoe infection was associated with a large proportion of the pine mortality in both survey areas (fig. 4). Forty percent of the dead Jeffrey pines on the San Bernardino and 60 percent on Laguna Mountain were heavily infested with dwarf mistletoe at the time of their death. Dwarf mistletoe was not the only important pine pathogen on the two southern California Forests. Root diseases were implicated in the death of nearly as many pines as were dwarf mistletoes (fig. 5). And sizable proportions of the pines in both areas had both root damage and heavy dwarf mistletoe infestations at the time of death (fig. 5). F. annosus was the major root pathogen in both areas.

Insects were also associated with most of the pathogen-induced mortality as was the case on the northern California Forests. Pathogen/insect complexes killed 70 percent of the trees of all species on the San Bernardino National Forest and 77 percent on Laguna Mountain.

The mortality survey results indicate that dwarf mistletoe is one of the most important causes of tree mortality on these two southern California Forests. The problem is especially acute because one of the two primary management goals is to provide for recreational use. The desirability of maintaining a tree cover on presently-forested land indefinitely intensifies the dwarf mistletoe impact. The option of making large regeneration cuts, thereby eliminating the parasite from the new stand is not feasible in such intensively used areas.

In the past, forest management in the southern California Forests was largely custodial, consisting primarily of sanitation-salvage cutting to reduce the number of insect high risk trees from the stands. Dwarf mistletoe suppression projects were separate activities, and were carried out only in limited areas. Insect suppression projects consisted of falling infested trees and treating them with chemicals.

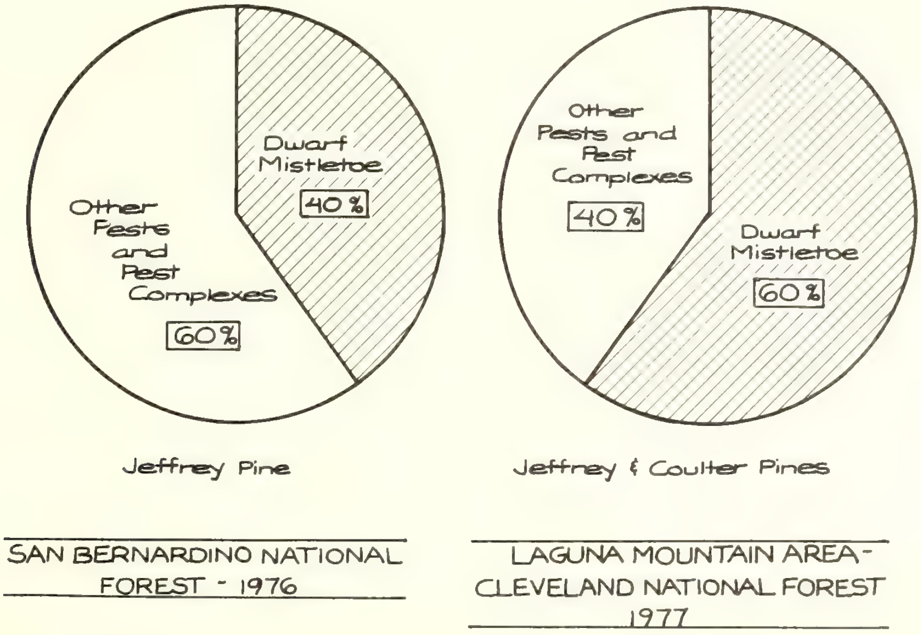

Figure 4 -- The relationship between dwarf mistletoe-induced mortality and total mortality of two yellow pine species on two southern California National Forests.

But insect and dwarf mistletoe control treatments alone have not resulted in the most desirable recreation stands. To some extent they may have been detrimental: the removal of trees for dwarf mistletoe control, insect control, and sanitation-salvage cutting appears to have intensified the annosus root disease problem by creating stumps suitable for infection. F. annosus infects a freshly cut stump by means of airborne spores, colonizes the stump and spreads from the roots of the infested stump to those of adjacent living trees, thereby causing an enlarging center of root damage and tree death.

The emphasis on southern California Forests is now changing from a holding action to one of active forest management. The management procedure is the one taught as a part of the California Region's silvicultural certification course (California Region, Forest Service 1976). A certified silviculturist examines the present stand structure in light of management objectives and prescribes treatments that will achieve and maintain a suitable future structure. Preventive and remedial insect and disease treatments are carried out as an integral part of the stand prescription, not as separate suppression activities.

The dwarf mistletoe prevention and suppression treatments that are incorporated into an integrated management system need not be complex. The treatments include the tools with which we are all familiar: species conversion, cutting of infected trees during thinnings, and overstory removal. But I believe the key is to incorporate them into one prescription whose aim is not dwarf mistletoe control but forest management.

GROWTH EFFECTS SURVEY

In 1977, we began testing PDI methods for a survey to measure the incidence of, and the growth loss caused by, insects and pathogens. We called this survey a Growth Effects Survey. Our approach for this survey is to

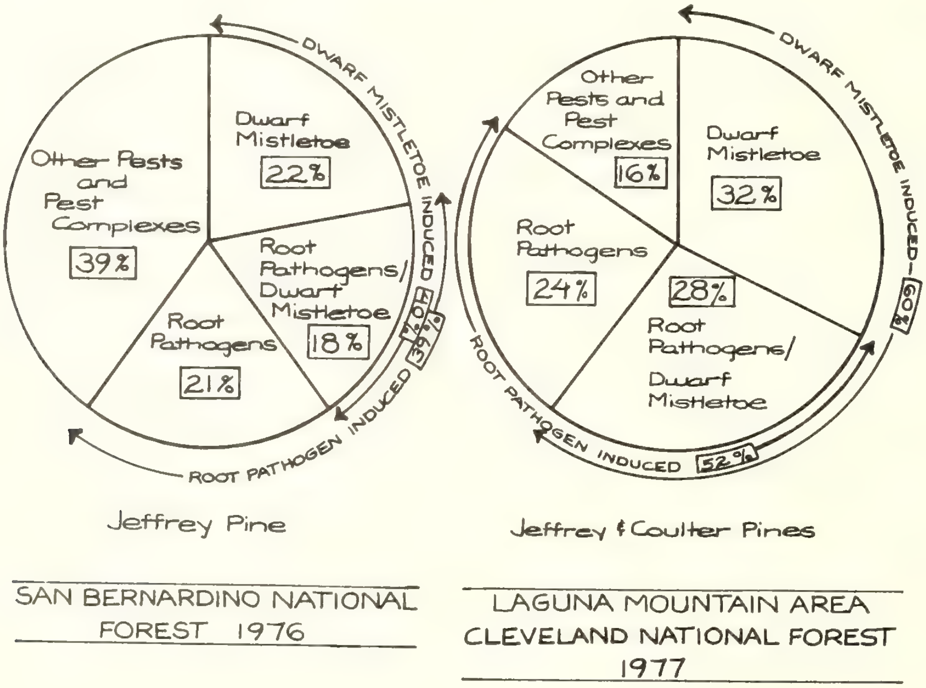

Figure 5 -- The relationship between dwarf mistletoe root pathogen-induced mortality and total mortality of two yellow pine species in two southern California National Forests. Fomes annosus was the major root pathogen.

collect pest data during the Compartment Inventory [3]. Trees measured by Compartment Inventory crews are also rated for insects, diseases, and defect. Information gained from Growth Effects Surveys are to be used mainly for two purposes:

1. Timber management: Estimates of the incidence of specific insects and pathogens and the damage (growth loss and defect) they are causing are obtained for compartments, and for strata within the compartments. These estimates are to be used in setting treatment priorities between strata, and for formulating stand prescriptions that include treatments for the prevention and reduction of insect and disease loss.

2. Administrative uses: When sufficient data have been collected from compartments in the Region, reliable estimates of growth loss and defect caused by dwarf mistletoes and other damaging pathogens and insects can be made.

Stratum Treatment Priority and Silvicultural Prescriptions

To date, data summaries are available for only one compartment, the Barton Flats Compartment on the San Bernardino National Forest (table 1). The compartment is divided into type strata that are sampled for growth and standing volume as well as pests. Thirty prism points were selected to represent each stratum (six randomly selected locations for L-shaped

Table 1. The incidence of pests in the Barton Flats Compartment, San Bernardino National Forest. (Sampling strata were based on tree species composition (pine or mixed conifers), average d.b.h. class (1 = 0-4.9"; 2 = 5-10.9"; 3 = 11-20.9"; 4 & 5 = 21" or more), and stand stocking density (percent crown closure: — = 0-19; = = 20-39; ≡ = 40-69; ≣ = 70-100).)

Stratum			Sample Size (No. Prism Points)	Percentage of Prism Points with:					
Type -	D.B.H. Class -	Stocking Density		Pest Problems	Ozone Injury	Annosus Root Disease	Dwarf Mistletoe	True Mistletoe	Other Pests
Pine -	Two Storied	All	30	33	17	7	0	3	6
Pine -	3	—	23	43	13	4	26	4	0
Pine	3	≡	27	11	0	0	4	0	7
Pine	4 & 5	All	30	67	23	20	0	3	21
MC	3	All	30	47	7	17	7	10	6
MC	4 & 5	All	28	61	14	7	7	7	26
All Strata			168	46	14	10	7	4	13

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[3] Compartments are land areas used in the National Forests of California for vegetative sampling. Ranging from 3,000 to 8,000 acres, they have boundaries that are defined by easily identified physical features.

clusters of 5 points). A few points were not usable and excluded from the summaries. Statistics on stratum growth, stocking, and pest incidence are used to write silvicultural prescriptions for stands within the strata.

Nearly half of the prism points had pest problems (table 1), thereby supporting the contention that the compartment is one needing management. A pest problem was defined as a "damaging level" of a pest:dwarf mistletoe rating of 4 or higher, *F. annosus* root disease on the plot, the presence of insect killed trees, or ozone symptoms on second-year pine needles.

Differences in pest intensity can be used to select strata and stands for immediate treatment -- and those in which treatment can be deferred. The proportion of prism points with pest problems varied by stratum ranging from 11 percent to 67 percent.

Pest data can also be used for making silvicultural prescriptions. A closer look at the pests in Barton Flats Compartment strata suggests that treatment options will vary between strata. For example, the two young sawtimber sized strata appear quite different with regard to pest problems. The P 3≡ stratum appears relatively free of pests. Removal of dwarf mistletoe infected trees during thinning may be the only special pest management necessary to maintain a relatively healthy young stand.

The P 3- stratum, on the other hand, may present a more difficult management problem. The stocking density is already low and the high incidence of dwarf mistletoe infection suggests more trees will die. Regeneration with pine will be a problem, unless the infected pine overstory is removed. But, the removal of the infected overstory, a substantial number of trees, is not desirable on this southern California Forest where maintaining an attractive appearance is important.

The mature pine stratum (P 4 & 5) had the greatest incidence of pest problems. Additional mortality may be expected -- especially in years of environmental stress. Stand prescriptions should allow for their replacement, either by release or regeneration cutting. The data suggest that dwarf mistletoe is not a major problem, and regeneration with pine appears feasible -- even near pine overstory trees. Ozone injury to pine is likely to be a continuing problem, however, and annosus root disease is an important consideration for both pine and fir.

Prescriptions are made for stands, not strata. Nevertheless, compartment inventory analysis results are used to project average stand growth, and to predict the general response of stands within the stratum to differen treatment options. Pest effects are also relevant to those predictions, and the pest data can be efficiently collected as a part of the compartment examination process. If additional information is needed for specific stands, additional compartment inventory data, includin pest data, can be collected.

Growth Loss

The second major goal of growth effects surveys is to provide growth loss estimates associated with each of the most damaging pests for administrative purposes. A larger data base is required before valid estimates can be made. Our approach is to compare stand growth in stands with pests, and those free of pests. Growth loss from all pests will be the difference between growth in infested and uninfested stands when differences in stocking density, site and species composition have been accounte for. Effects of individual pests and pest complexes will be expressed as a portion of the total loss.

CONCLUSIONS

Dwarf mistletoes are major contributors to tree mortality. Dwarf mistletoe-induced mortality is usually not a major problem in timber producing forests where even-aged management is practiced and when the pathogen will be eliminated or reduced to low levels during thinnings or eliminated at the end of relatively short rotations. But dwarf mistletoe-induced mortality is especially important in recreation areas, and other areas where management options are reduced. The value of the trees, the rates at which dwarf mistletoes build up in the stands, and the goal of maintaining a tree cover for long periods makes the dwarf mistletoes an important management consideration. Regeneration with susceptible tree species is especially difficult if the removal of infected overstory trees is preclude

Dwarf mistletoes are but one important class of tree pests, and pest management system must integrate treatments for the entire comple of pests. Failure to do so may limit the effectiveness of dwarf mistletoe control, since the anticipated benefits of reduced mortality and increased growth may not be realized if other pests are also present. At least one dwarf mistletoe control project, on Laguna Mountain, aggravated the root disease problem by creating stumps that served as *F. annosus* infection courts.

Stand management objectives can best be accomplished through the integration of pest management prescriptions and stand prescriptions. Stand management, not dwarf mistletoe control alone, is usually required to attain and maintain the desired stand structure. The process is most efficient when dwarf mistletoe (and other pest) considerations are built into forest/compartment/stand inventories, stand prescriptions, and stand treatments. If dwarf mistletoe levels are reduced during stand management, dwarf mistletoe damage to the stand will be prevented, and fewer special remedial control efforts will be required in the future.

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LITERATURE CITED

Bega, R. V., D. Dotta, D. R. Miller and R. S. Smith, Jr.
1966. Root disease survey at Boggs Mountain State Forest, California. Plant Dis. Reporter. 50:439-440.

Cobb, F. W., Jr., J. R. Parmeter, Jr., D. L. Wood and R. W. Stark.
1974. Root pathogens as agents predisposing ponderosa pine and white fir to bark beetles. Fourth Conf. on *Fomes annosus*. Athens, Ga. p. 8-15.

California Region, Forest Service
1977. R5 compartment inventory handbook. 46 pages. San Francisco, Calif.

Frye, R. H., and T. D. Landis.
1975. Biological evaluation -- mountain pine beetle and dwarf mistletoe, Lake Creek Area, San Carlos Ranger District, Pike-San Isabel National Forest. USDA Forest Serv., Rep. R-2-75-4, Lakewood, Colo. 10 p.

Hawksworth, F. G., and A. A. Lusher.
1956. Dwarf mistletoe survey and control on the Mescalero-Apache Reservation, New Mexico. J. For. 56(6):384-391.

Johnson, D. W., L. C. Yarger, C. D. Minnemeyer and V. E. Pace.
1976. Dwarf mistletoe as a predisposing factor for mountain pine beetle attack of ponderosa pine on the Colorado Front Range. USDA Forest Serv., Region 2, Tech. Rep. R2-4. Lakewood, Colo. 7 p.

Miller, D. L., and A. D. Partridge.
1974. Root rot indicators in grand fir. Plant Dis. Reporter 58(3):275-276.

Miller, J. M., and F. P. Keen.
1960. Biology and control of western pine beetle. USDA Misc. Publ. 800. 381 p.

Parker, D. L., and E. L. Stipe.
1974. Does mountain pine beetle select and kill dwarf mistletoe-infected lodgepole pine? USDA Forest Serv., Region 4. Ogden, Utah. 4 p.

Parker, D. L., J. W. Walters, and A. H. Smith.
1975. Assessment of factors causing ponderosa pine mortality on the Lincoln National Forest. USDA Forest Serv., Region 3, Albuquerque, N.M. 19 p.

Partridge, A. D., and D. L. Miller.
1972. Bark beetles and root rots related in Idaho conifers. Plant Dis. Reporter 56:498-500.

Stark, R. W., and F. W. Cobb, Jr.
1969. Smog injury, root diseases and bark beetle damage in ponderosa pine. Calif. Agric. 23(9):13-15.

DEVELOPMENT OF GROWTH AND YIELD MODELS FOR DWARF MISTLETOE-INFESTED STANDS[1]

Carleton B. Edminster[2]

Abstract: Forest stand growth and yield models have conceptual, developmental, and output utility. Three categories of stand models are commonly recognized: models requiring individual tree records with intertree distances; models requiring individual tree records without intertree distances; and models requiring whole stand summary information only. Relationships describing the development of dwarf mistletoe infestation and effects on stand growth and yield may be incorporated in all three model types depending on stand structure and need for detailed information by land managers.

INTRODUCTION

Models of biological systems are typically expressions of sets of "fuzzy" laws in mathematical terms. A fuzzy law is a biological, physical, or mathematical concept which is not known with a high degree of accuracy. In contrast, many physical systems may be characterized by sharp laws which are known to a very high degree of accuracy (Zadeh 1965).

Usually, it is not the laws which are fuzzy or sharp but our perception, understanding, and expression of them. All models are defective to some degree; some aspects of the modelers' concepts do not apply to the problem at hand. Further complications arise because we usually synthesize predictive models from limited data representative of small experimental areas. All this would seem to indicate that models of biological systems would usually be of limited value. However, models of systems do have value at three recognized levels: (1) conceptual, (2) developmental, and (3) output (Innis 1973).

First, conceptualizing a system in terms of a model provides a frame of reference. Conceptual utility results from identifying major components of the system and major interactions among components.

Second, developmental utility results from the usefulness of what the modeler learns from the process of constructing the model. The modeler is forced into very precise, if not necessarily accurate, thinking. The modeler must deal with interactions of systems components and resolve inconsistencies from the conceptual stage. Model development requires that complex, seemingly intractable systems be broken down into relatively simple pieces. Casual synthesis of the pieces of the modeled system may produce unstable model behavior. Only careful formulation can lead to important insights into system dynamics. Experience in developing models will lead to enhanced perception and understanding of the system. In addition, the modeling effort can be used to guide future research to fill gaps in current knowledge.

The third value of system modeling lies in user benefits or output utility. Output utility is derived by persons outside the modeling effort from model documentation and computer printed output. Many existing models have large developmental utility but are of limited practical use. This is probably due to our current level of modeling expertise. The land manager needs usable tools to aid in decisionmaking. Models which require unavailable data, cost too much to use, or produce inaccurate results are not efficient tools. Potential model users must be included in the modeling process from the beginning to insure output utility.

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MODELING FOREST PESTS AND FOREST STANDS

Most modeling has dealt with either forest pests or forest stands, with little regard to building an integrated management framework. This situation has resulted from the makeup of modeling groups which all too often are composed of specialists in only one subject area. We are concerned with developing growth and yield models for dwarf mistletoe-infested stands. To accomplish this, an integrated pest-host model to effectively describe the complex interactions of the pest-host system is essential.

Modeling Forest Pest Populations

Studies of pest populations seem to focus on the pest's life cycle, factors controlling its development, and association with its host. The life table technique, with many modifications, has been used in the study of forest insects. Examples of the technique for forest pests include:

Mountain pine beetle (Dendroctonus ponderosae) in Black Hills ponderosa pine (Pinus ponderosa) (Knight 1959) and in lodgepole pine (P. contorta) (Cole 1974).

Pine saw flies (Neodiprion fulviceps) (Dahlsten 1967).

Needle miner (Recurvaria starki) (Stark 1952).

Dwarf mistletoes (Arceuthobium americanum and A. vaginatum) (Hawksworth 1965).

Progress is being made in quantifying interactions of pests and hosts. The association of mountain pine beetle dynamics in lodgepole pine stands with stand diameter structure, phloem thickness, and host resistance have been quantified in empirical models (Cole et al. 1976, Berryman 1976). A model for the spread and intensification of western dwarf mistletoe (A. campylopodum) in thinned stands of sapling ponderosa pine has been developed by Strand and Roth (1976). Limitations of the model are assumptions of even tree spacing and uniform tree height. However, dwarf mistletoe development is related to spacing and tree crown characteristics, so that provisions are available for generalization to more realistic forest stands. This model is an excellent example of the developmental work needed in building integrated models. General pest population models require integration of submodels of intensification (or productivity) and spread (or migration). Complex pest-host-environment interactions then must be quantified before the effects of pests on growth and yield of host populations can be examined.

Modeling Forest Stands

Few models of growth and yield of forest stands are being used by land managers, largely due to low output utility. Most of the models have been empirical rather than theoretical or process oriented. An empirical model should adequately describe the results of biological processes without trying to simulate the complex processes themselves. Empirical models can be formulated in very simple regression type relations and sophisticated mathematical functions. Process models of tree development may describe system behavior at a level of resolution too detailed for land managers. An example is modeling tree physiology as an aggregation of physical and chemical processes to simulate the mechanisms of photosynthesis, respiration, translocation, and assimilation.

Stand projection methods and models give good estimates of current growth which can be used for short-term projections based on current management conditions (Larson and Goforth 1974). These methods are not well adapted to making long-term projections or evaluating alternative management strategies since only current average growth and mortality rates are used. These rates do not allow for changes due to treatment. A few stochastic or probabilistic models have been developed for stand projection. A notable example is a Markov model developed by Peden et al. (1973). Also, Moser (1972) formulated a system of differential equations to describe development of an uneven-aged stand. The introduction of cultural treatments and possible long-term structural and species changes seems rather difficult in both of these models.

Fairly simple stand models may be constructed to adequately describe the development of even-aged stands, but these models will probably be totally inadequate for uneven-aged stands. An even-aged stand is composed of one main age class over an area large enough to be recognized as a management unit. This represents a rather simple forest condition. An uneven-aged stand may include two to many age classes, and arrangement may vary from even-aged groups to mixtures of all age classes over small areas.

Curtis (1976) provides an excellent summary of differences in yield prediction methods for even-aged and uneven-aged stands. Some of the complicating factors in going from an even-aged model structure to uneven-aged include: (1) possible inadequacy of site index for site classification, (2) need for larger experimental areas to include a full range of stand conditions, (3) possible unstable species composition and stand structure, (4) need for a meaningful measure of tree competition and requirements for reproduction, and (5) allowance for a wide range of possible silvicultural treatments.

Munro (1974) distinguishes three "modeling philosophies" to conveniently characterize stand models by the primary model units and intertree dependency. The first philosophy assumes the primary unit in the stand model is the individual tree, requiring intertree distance relationships. The second philosophy again assumes the individual tree is the primary unit, but intertree distances are not necessary. The third philosophy assumes the stand itself is the primary unit; individual tree information and intertree distances are not needed.

Stand models which use the individual tree as the primary unit and are distance dependent can produce very detailed information about the structure and development of the stand. This type of model has been used by Newnham (1964), Lee (1967), Mitchell (1969), Bella (1971b), Arney (1972), Ek and Monserud (1974), and others for a variety of tree species. Each of these models depends on a measure of intertree competition related to distances from a subject tree to neighboring trees and the size of the subject tree relative to its neighbors. This measure of competition often takes the form of overlapping circles proportional in size to the competitive status of the subject tree and its neighbors (Bella 1971a). An alternative method based on available growing space polygons has been developed by Adlard (1974).

Models which include crown dimension increments (Mitchell 1969, Arney 1972) have the potential for studying intertree competition, bark beetle attack and migration, insect defoliation, top dieback, and dwarf mistletoe spread and intensification. The linkage of such stand models with the dwarf mistletoe model of Strand and Roth (1976) seems fairly straightforward. Clearly, such stand models can be used in examining effects of thinning and tree spacing and can be adapted to even-aged or uneven-aged stands. The major disadvantage of distance dependent modeling is the requirement for a stem map and excessive computer time to assess intertree competition (Munro 1974). Operational use of such models is limited since stem maps are not generally available. Most of these models have the provision for generating an artificial stem map to be used with sample tree measurements, but then the model is really functioning in a distance independent mode. Perhaps development of underlying spatial patterns as proposed by Matérn (1971) can be used in generating more realistic stem maps.

Stand models which use the individual tree as the primary unit and are distance independent can be more efficient for operational use in studying the effects of cultural treatments. This type of stand model does not require intertree distance measurements. Sample tree measurements are more likely to be available for input to this model, and tedious computations of competition measures are eliminated. Examples of this type of model have been produced by Botkin et al. (1972) and the Stand Prognosis Model by Stage (1973, 1975) with additions for mortality by Hamilton and Edwards (1976). A Stand Outbreak Model has been added to the Prognosis Model to project the interaction of the tussock moth (Orgyia pseudotsugata) and Douglas-fir (Pseudotsuga menziesii) stands. Mountain pine beetle impact has also been added for lodgepole pine stands.

These models are capable of producing detailed tree and stand information, including stand and stocking tables. Because stem maps are eliminated, fast computing time permits examination of many alternative thinning and spacing strategies. These models are also adaptable to even-aged and uneven-aged stands. The major disadvantage of individual tree models which are distance independent is that the growth of a specific tree can not be predicted with any reliability. Examination of development of individual tree crowns and boles also is not reliable. A model for intensification of dwarf mistletoe and resultant loss of growth and yield could be integrated with such a model. A dwarf mistletoe spread model might not be quite so easy to incorporate, depending on variability of stand spatial patterns.

Whole stand models which are distance independent are probably most familiar to foresters. The conventional normal yield table is an example of such a model. This modeling philosophy holds that the whole stand is the primary unit as characterized by some average values, such as average tree d.b.h., height, volume, age, and basal area or number of stems per unit area. This model has the capability of examining a variety of thinning and spacing strategies, and uses computer time very efficiently. Whole stand models do not provide any individual tree information, and stand and stocking tables are usually lacking. Whole stand models are capable of predicting yields for even-aged stands of a single species, but more complex age or species composition generally can not be simulated. Use of conventional inventory information for program input makes this model attractive for operational use.

Two whole stand models which are operational have been developed for dwarf mistletoe-infested stands: LPMIST for even-aged lodgepole pine in the central Rocky Mountains (Myers et al. 1971), and SWYLD2 for even-aged and two-storied stands of southwestern ponderosa pine (Myers et al. 1976). The extension of whole stand models to a two-storied stand in SWYLD2 probably represents the limit of generalization from true even-aged conditions. These programs have been combined into a new program, RMYLD (Edminster 1978), designed to provide for more flexible management strategies and a wider range of stand conditions.

Dwarf mistletoe relationships in these programs were added as adjustments to noninfested stand performance. These relationships reflect only average dwarf mistletoe intensification in infested stands, and the ability to measure spread is lacking. This demonstrates that the primary unit in the stand model will be on the same level as the pest model. Dixon (1977) has incorporated whole stand growth and yield relationships into a spread and intensification model for southwestern ponderosa pine. These models attempt to handle many of the silvicultural treatments for the host species as described by Alexander (1974), Hawksworth et al. (1977), Schubert (1974), and Myers (1974), but the limitation to simple stand structure is a serious shortcoming, in many instances.

INTEGRATED DWARF MISTLETOE AND FOREST STAND MODELS

Development of a successful integrated model requires formation of a modeling team before the conceptual stage. This team should be composed of people with a wide variety of expertise and experience (i.e., a mensurationist, silviculturist, forest pathologist, and mathematical statistician from research and a forest manager and disease specialist from the projected user groups). As mentioned earlier, users are included hopefully to insure model output utility. The ultimate goal of the modeling effort should be to develop a usable management tool.

The workings of such a team have been summarized by Anderson et al. (1976) for the lodgepole pine-mountain pine beetle system. The steps of developing impact models, pest population dynamics models, pest-host interaction models, and stand models also apply to dwarf mistletoe-infested forest stands. Conceptual stand models are available to match any combination of tree ages, species, and sizes, Development of complementary pathogen models also is underway. The modeling philosophy must be chosen early in model development. This will be dictated largely by stand and dwarf mistletoe conditions of interest, as well as the kind of information needed by the user (Murdie 1971).

Data input requirements must be kept reasonable. The model should be kept as simple as possible and still produce accurate results. As the model becomes more complex, developmental costs increase, user costs increase, and use decreases.

Bruce (1977) provides an excellent summary of what to expect of the modeling effort. Differences will occur between predicted model results and stand performance. Modeling is an evolutionary process, and at each stage, the model should become more accurate, efficient, and useful.

LITERATURE CITED

Adlard, P. G.
1974. Development of an empirical competition model for individual trees within a stand. p. 22-37. In Growth models for tree and stand simulation: Proc. IUFRO working party S4.01 in 1973. Jöran Fries, ed. Royal Coll. For. Res. Notes 30, Stockholm, Sweden.

Alexander, Robert R.
1974. Silviculture of subalpine forests in the central and southern Rocky Mountains: The status of our knowledge. USDA For. Serv. Res. Pap. RM-121, 88 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Anderson, L. S., A. A. Berryman, D. G. Burnell, W. H. Klein, E. L. Michalson, A. R. Stage, and R. W. Stark.
1976. The development of predictive models in the lodgepole pine-mountain pine beetle ecosystem. p. 149-164. *In* Modeling for pest management. Concepts, techniques, and applications. Ramamohan L. Tummala, Dean L. Haynes, and Brian A. Croft, eds. Mich. State Univ., East Lansing.

Arney, James D.
1972. Computer simulation of Douglas-fir tree and stand growth. Ph.D. Thesis, Oregon State Univ., Corvallis, 79 p.

Bella, I. E.
1971a. A new competition model for individual trees. For. Sci. 17:364-372.

Bella, I. E.
1971b. Simulation of growth, yield and management of aspen. Ph.D. Thesis, Univ. of British Columbia, Vancouver, 190 p.

Berryman, Alan A.
1976. Theoretical explanation of mountain pine beetle dynamics in lodgepole pine forests. Environ. Entomol. 5:1225-1233.

Botkin, D. B., J. F. Janak, and J. R. Wallis.
1972. Rationale, limitations, and assumptions of a northeastern forest growth simulator. IBM J. Res. Dev. 16:101-116.

Bruce, David.
1977. Yield differences between research plots and managed forests. J. For. 75:14-17.

Cole, Walter E.
1974. Competing risks analysis in mountain pine dynamics. Res. Popul. Ecol. 15:183-192.

Cole, W. E., G. D. Amman, and C. E. Jensen.
1976. Mathematical models for the mountain pine beetle-lodgepole pine interaction. Environ. Entomol. 5:11-19.

Curtis, Robert O.
1976. Growth and yield in uneven-aged stands. p. 81-97. *In* Uneven-aged silviculture and management in the western United States. Proc. USDA For. Serv. In-Service workshop. Redding, Calif.

Dahlsten, D. L.
1967. Preliminary life tables for saw flies in the *Neodiprion fulviceps* complex. Ecology 48:275-289.

Dixon, Gary E.
1977. A spread and intensification model for mistletoe in ponderosa pine. Ph.D. Thesis, Colo. State Univ., Fort Collins, 135 p.

Edminster, Carleton B.
1978. RMYLD: Computation of yield tables for even-aged and two-storied stands. Res. Pap. RM-199. 26 p. Rocky Mt. For. and Range Exp. Stn., For. Serv., U.S. Dep. Agric., Fort Collins, Colo.

Ek, Alan R., and Robert A. Monserud.
1974. FOREST: A computer model for simulating the growth and reproduction of mixed species forest stands. Res. Rep. A2635. Sch. Nat. Resour., Univ. of Wisc., Madison, 13 p.

Hamilton, David A., Jr., and Bruce M. Edwards.
1976. Modeling the probability of individual tree mortality. USDA For. Serv. Res. Pap. INT-185, 22 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Hawksworth, Frank G.
1965. Life tables for two species of dwarf mistletoe I. Seed dispersal, interception, and movement. For. Sci. 11:142-151.

Hawksworth, Frank G., Thomas E. Hinds, David W. Johnson, and Thomas D. Landis.
1977. Silvicultural control of dwarf mistletoe in young lodgepole pine stands. USDA For. Serv., Reg. 2, For. Insect and Dis. Manage., Tech. Rep. R2-10. 13 p.

Innis, George.
1973. Simulation of ill-defined systems: some problems and progress. Simul. Today 9:33-36.

Knight, F. B.
1959. Partial life tables for the Black Hills beetle. J. Econ. Entomol. 52:1200-1202.

Larson, Robert W., and Marcus H. Goforth.
1974. TRAS-a timber volume projection model. USDA For. Serv. Tech. Bull. 1508. 15 p.

Lee, Yam.
1967. Stand models for lodgepole pine and limits to their application. Ph.D. Thesis, Univ. of British Columbia, Vancouver, 331 p.

Matérn, B.
1971. Doubly stochastic Poisson processes in the plane. p. 195-206. In Statistical Ecology, Vol. 1, Spatial Patterns and Statistical Distributions. G. P. Patil, E. C. Pielou, W. E. Waters, eds. Penn. State Stat. Ser.

Mitchell, K. J.
1969. Simulation of the growth of even-aged stands of white spruce. Sch. For., Yale Univ. Bull. No. 75, 48 p.

Moser, John W., Jr.
1972. Dynamics of an uneven-aged forest stand. For. Sci. 18:184-191.

Munro, Donald D.
1974. Forest growth models--a prognosis p. 7-21. In Growth models for tree and stand simulation: Proc. IUFRO working party S4.01 in 1973. Jöran Fries, ed. Royal Coll. For. Res. Notes 30, Stockholm, Sweden.

Murdie, G.
1971. Simulation of the effects of predator/parasite models of prey/host spatial distribution. p. 215-229. In Statistical Ecology, Vol. 1, Spatial Patterns and Statistical Distributions. G. P. Patil, E. C. Pielou, W. E. Waters, eds. Penn. State Stat. Ser.

Myers, Clifford A.
1974. Multipurpose silviculture in ponderosa pine stands of the Montane Zone of central Colorado. USDA For. Serv. Res. Pap. RM-132, 15 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Myers, Clifford A., Frank G. Hawksworth, and James L. Stewart.
1971. Simulating yields in managed, dwarf mistletoe-infested lodgepole pine stands. USDA For. Serv. Res. Pap. RM-72, 15 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Myers, Clifford A., Carleton B. Edminster, and Frank G. Hawksworth.
1976. SWYLD2: Yield tables for even-aged and two-storied stands of southwestern ponderosa pine, including effects of dwarf mistletoe. USDA For. Serv. Res. Pap. RM-163, 25 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Newnham, R. M.
1964. The development of a stand model for Douglas-fir. Ph.D. Thesis, Univ. of British Columbia, Vancouver, 201 p.

Peden, L. M., J. S. Williams, and W. E. Frayer.
1973. A Markov model for stand projection. For. Sci. 19:303-314

Schubert, Gilbert H.
1974. Silviculture of southwestern ponderosa pine: The status of our knowledge. USDA For. Serv. Res. Pap. RM-123, 71 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Stage, Albert R.
1973. A model for the prognosis of forest stand development. USDA For. Serv. Res. Pap. INT-137, 32 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Stage, Albert R.
1975. Prediction of height increment for models of forest growth. USDA For. Serv. Res. Pap. INT-164, 20 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Stark, R. W.
1952. Analysis of a population sampling method for the lodgepole needle miner in Canadian Rocky Mountain Parks. Can. Entomol. 84:316-321.

Strand, M. A., and L. F. Roth.
1976. Simulation model for spread and intensification of western dwarf mistletoe in thinned stands of ponderosa pine saplings. Phytopathology 66:888-895.

Zadeh, L. A.
1965. Fuzzy sets and systems. Symp. on Syst. Theory. Polytech. Press, Polytech. Inst. Brooklyn, N. Y. p. 29-37.

Program Summary

NEEDED RESEARCH AND DEVELOPMENT TO IMPROVE DWARF MISTLETOE CONTROLS[1]

J. R. Parmeter, Jr., F. G. Hawksworth, and R. F. Scharpf[2]

Abstract: The speakers at this symposium have summarized the latest information on and experience with dwarf mistletoe control through forest management. This information, developed over many years by researchers and managers, provides a firm foundation for the control strategies we have discussed these past three days. The questions raised by speakers and participants indicate that the latest word should not be the last, however. Additional information is needed to refine present approaches to control and to explore new control possibilities.

The following is a brief outline of research and development needs as they were highlighted by speakers and participants. The list is not exhaustive, nor does it provide specific details. We hope that it does indicate the scope and magnitude of the job ahead.

In the general area of dwarf mistletoe biology, some important information is lacking or incomplete. Broad aspects of host specialization have been established for most species, but needed details, especially for A. tsugense and A. occidentale/A. campylopodum, are yet unclear. The range and significance of "crossover" possibilities and their relationship to stand conditions need clarification and evaluation. The basis for the "exclusion principle" (if the principal parasite of a certain host is present in an area, other dwarf mistletoes rarely parasitize that tree) needs investigation, since it may have important implications in the management of mixed stands.

Information on interactions among dwarf mistletoes and other forest pests is sketchy. Preliminary evidence indicates that mistletoes predispose trees to bark beetles and perhaps to root diseases, but the influence of dwarf mistletoes on bark beetle dynamics, root diseases, or other pests needs confirmation and evaluation. Animals or birds may provide for non-ballistic spread of mistletoe seeds into uninfested areas. The frequency, range, and implications of such spread need evaluation.

The incidence, behavior, and impact of dwarf mistletoes vary with differences in geography, topography, habitat type, and environment in ways that are poorly understood. Determination of the bases for these variations may permit recognition of presently unrecognized factors or stand features that limit dwarf mistletoes or their impact.

Most general relationships between forest stand dynamics and dwarf mistletoe damage are well established. Quantitative differences in these relationships among the many host/mistletoe combinations, stand types, and geographic areas are needed to establish accurate rate functions for predictive models and to provide data for sound management decisions. Among these functions, the quantification of : (1) vertical spread rates in relation to host growth and crown closure rates, (2) "laddering" or "cross-walking" rates in relation to stand density, and (3) spread, increase, and damage rates in relation to stand manipulations deserve special emphasis.

Questions regarding effects of dwarf mistletoes on wood quality needs answers in order to develop accurate impact assessments, especially where stem infections are involved.

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[1] Presented at the Symposium on Dwarf Mistletoe Control Through Forest Management, Berkeley, California, April 11-13, 1978.

[2] Respectively: Professor of Plant Pathology, Univ. of Calif., Berkeley; Forest Pathologist, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.; and Forest Pathologist, Pacific Southwest Forest and Range Experiment Station, Berkeley, Calif.

The 6 (or 7) class rating system provides a good standard to quantify dwarf mistletoe intensity, but further data on the relationship of intensity to damage with different host/mistletoe combinations under different stand conditions and management strategies are needed. Additionally, the standard intensity rating system may need modification for small trees.

A pressing need frequently mentioned is that for models to provide accurate stand growth prediction, impact assessment, and cost/benefit analysis. The development of such models for different forest types, regions, and mistletoes species should receive high priority.

Along with research directed to specific problems and needed refinements, effort should also be directed to exploratory or basic research that might lead to the development of new approaches to control. Resistance to dwarf mistletoes has been demonstrated, and possibilities for the development of resistant selections or the elaboration of resistance mechanisms should be explored. While native insects and diseases have not shown promise as biological controls, the search for effective exotic parasites of mistletoes should be continued. Satisfactory chemical controls have not been discovered, but some level of testing should continue. Either chemical or biological controls could provide valuable adjuncts to silvicultural controls.

At present, fire has proved useful mainly in clearing areas of infected residual trees following logging. Fire may also be useful in eliminating brooms or infected branches from the lower crowns of small trees, but research is needed to evaluate such uses.

As the maintenance of trees in parks, high-use recreational areas, and forest home sites becomes increasingly important, the development of special control methods (broom pruning, shoot removal, etc.) for different host/mistletoe combinations becomes increasingly important and deserving of special research effort.

We have come a long way down some important roads to dwarf mistletoe control. One job ahead is to straighten and widen these roads so that they take us most directly and efficiently to our goals. Other roads have scarcely been explored or have proved too difficult to use at present. These should be investigated, and where they show promise, developmental work should begin. Both refinement and exploration require our attention and support.

LITERATURE ON THE DWARF MISTLETOES: DAMAGE AND CONTROL

F. G. Hawksworth[1] and R. F. Scharpf[2]

The literature on the dwarf mistletoes (Arceuthobium spp.) is extensive. For our FAMULUS mistletoe literature retrieval system (Scharpf and others 1976) we have assembled nearly 2,500 references on these serious parasites of coniferous trees. For this literature review, we have selected the most important references dealing with damage and control of the dwarf mistletoes of the United States and Canada.

Details on nomenclature, hosts, and distribution of the dwarf mistletoes are given by Hawksworth and Wiens (1972).

1. ARCEUTHOBIUM ABIETINUM - Fir dwarf mistletoe.

PRINCIPAL HOSTS: Abies concolor, A. magnifica, A. grandis.

DISTRIBUTION: U.S.: Arizona, California, Nevada, Oregon, Utah, and Washington

DAMAGE: Aho and Hadfield 1975; Byler 1975; California Forest Pest Control Action Council 1968; Craig and Maguire 1949; Fowells and Schubert 1956a; Gordon 1973a, 1973b; Gordon and Roy 1973; Hallin 1957; Kimmey 1957a, 1957b; Kimmey and Bynum 1961; Kingsley 1977; Parmeter and Scharpf 1963; Pong and Jackson 1971; Scharpf 1964, 1969b, 1977; Scharpf and Bynum 1975; Scharpf and Parmeter 1967; Wilcox and others 1973; Wright 1942.

CONTROL: Craig and Maguire 1949; Gordon and Roy 1973; Kimmey 1957a; Kingsley 1977; Parmeter and Scharpf 1963; Scharpf 1964; 1969a, 1969b, Scharpf and Parmeter 1967.

2. ARCEUTHOBIUM AMERICANUM - Lodgepole pine dwarf mistletoe.

PRINCIPAL HOSTS: Pinus contorta, P. banksiana.

DISTRIBUTION: CANADA: Alberta, British Columbia, Manitoba, Ontario, and Saskatchewan. U.S.: California, Colorado, Idaho, Montana, Oregon, Utah, Washington, and Wyoming.

DAMAGE: Alexander and others 1976; Baranyay and Safranyik 1970; Dobie and Britneff 1975; Dooling 1974; Hawksworth 1958; Hawksworth and Hinds 1964; Muir 1965; Myers and others 1971; Piirto and others 1974; Roe and Amman 1970; Weir 1916a; Ziegler 1978.

CONTROL: Alexander 1974, 1975; Baranyay 1970, 1975; Baranyay and Smith 1972; Brown 1977; Dooling 1974; Gill and Hawksworth 1964; Hawksworth and Johnson 1961; Hawksworth and others 1977; Kimmey 1957b; Kimmey and Graham 1960; LeBarron 1952; Lotan and Alexander 1973; Schwandt 1977.

3. ARCEUTHOBIUM APACHECUM - Apache dwarf mistletoe.

PRINCIPAL HOST: Pinus strobiformis.

DISTRIBUTION: U.S.: Arizona, New Mexico.

DAMAGE: Andrews and Daniels 1960; Gooddi 1938; Gottfried and Embry 1977; Mathias 1977.

CONTROL: Gottfried and Embry 1977.

4. ARCEUTHOBIUM BLUMERI (No common name)

PRINCIPAL HOST: Pinus strobiformis.

DISTRIBUTION: U.S.: Arizona

DAMAGE: Mathiasen 1977.

CONTROL: None.

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5. ARCEUTHOBIUM CALIFORNICUM - Sugar pine dwarf mistletoe.

PRINCIPAL HOSTS: Pinus lambertiana. P. monticola.

DISTRIBUTION: U.S.: California, Oregon.

DAMAGE: California Forest Pest Control Action Council 1968; Fowells and Schubert 1956b; Kimmey 1957b; Kingsley 1977; Offord 1961; Scharpf and Hawksworth 1968; Struble 1942, 1965; Weir 1977.

CONTROL: Scharpf and Hawksworth 1968.

6. ARCEUTHOBIUM CAMPYLOPODUM - Western dwarf mistletoe.

PRINCIPAL HOSTS: Pinus ponderosa var. ponderosa, P. jeffreyi.

DISTRIBUTION: U.S.: California, Nevada, Oregon, and Washington.

DAMAGE: Byler 1975; California Forest Pest Control Action Council 1968; Childs and Edgren 1967; Childs and Wilcox 1966; Kimmey and Mielke 1959; Kingsley 1977; Knutson 1970, 1972, Munns 1919; Parmeter and Scharpf 1972; Roth 1953, 1971; Schwandt 1977; Shea 1964a; Shea and Belluschi 1965; Strand and Roth 1976; Wagener 1961, 1965; Weir 1916a, 1918; Weir 1977.

CONTROL: Barrett 1973; Childs 1963; Flora 1966a, 1966b; Hallin 1959; Kimmey 1957b; Kimmey and Graham 1960; Kimmey and Mielke 1959; Kingsley 1977; Knutson 1975; Russell 1971; Schwandt 1977; Shea 1964b; Shea and Lewis 1971; Strand and Roth 1976; Weir 1977.

7. ARCEUTHOBIUM CYANOCARPUM - Limber pine dwarf mistletoe.

PRINCIPAL HOSTS: Pinus flexilis, P. aristata, P. albicaulis.

DISTRIBUTION: U.S.: California, Colorado, Idaho, Montana, Nevada, Utah, and Wyoming.

DAMAGE: Chick 1936; Gillman and Bailey 1977; Landis and others 1977; Urban 1968; Williams and others 1972.

CONTROL: Urban 1968.

8. ARCEUTHOBIUM DIVARICATUM - Pinyon dwarf mistletoe.

PRINCIPAL HOSTS: Pinus edulis, P. monophylla.

DISTRIBUTION: U.S.: Arizona, California, Colorado, Nevada, New Mexico, Texas, and Utah.

DAMAGE: Hreha 1978; Walters 1976.

CONTROL: None.

9. ARCEUTHOBIUM DOUGLASII: Douglas-fir dwarf mistletoe.

PRINCIPAL HOST: Pseudotsuga menziesii.

DISTRIBUTION: CANADA: British Columbia. U.S.: Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Texas, Utah, and Wyoming.

DAMAGE: Andrews and Daniels 1960, California Forest Pest Control Action Council 1968; Chick 1936; Dunning 1923; Gottfried and Embry 1977; Graham 1961; Haglund and Dooling 1972; Hawksworth and Lusher 1956; Hopkins 1959; Hutchinson and Roe 1962; Jones 1974; Kimmey and Graham 1960; Kingsley 1977; Pierce 1960; Schwandt 1977; Shea 1960, 1963a, 1963b; Weir 1916a, 1918.

CONTROL: Baranyay and Smith 1972; Graham 1961; Jones 1974; Kimmey 1957b; Kimmey and Graham 1960; Kingsley 1977; Schwandt 1977; Shea 1960, 1963a; Wellner and Ryker 1973.

10. ARCEUTHOBIUM GILLII - Chihuahua pine dwarf mistletoe.

PRINCIPAL HOST: Pinus chihuahuana.

DISTRIBUTION: U.S.: Arizona, New Mexico.

DAMAGE: Loomis 1972; Walters 1976.

CONTROL: Walters 1976.

11. ARCEUTHOBIUM LARICIS - Larch dwarf mistletoe.

PRINCIPAL HOST: Larix occidentalis.

DISTRIBUTION: CANADA: British Columbia. U.S.: Idaho, Montana, Oregon, and Washington.

DAMAGE: Baranyay and Smith 1972; Boe 1958; Dooling 1971; Graham 1960, 1964; Hutchinson and Roe 1962; McGregor and Williams 1974; On and Dooling 1969; Pierce 1960; Schwandt 1977; Smith and Baranyay 1970; Weir 1916a, 1916b; Weir 1977.

CONTROL: Baranyay and Smith 1972; Dooling 1971, 1974; Kimmey and Graham 1960; Schwandt 1977; Smith and Baranyay 1970; Weir 1916a; Weir 1977.

12. ARCEUTHOBIUM MICROCARPUM - Western spruce dwarf mistletoe.

PRINCIPAL HOSTS: Picea engelmannii, P. pungens.

DISTRIBUTION: U.S.: Arizona, New Mexico.

DAMAGE: Acciavatti and Weiss 1974; Andrews and Daniels 1960; Gottfried and Embry 1977; Hawksworth and Graham 1963; Jones 1974; Mathiasen 1977; Walters 1976.

CONTROL: Gottfried and Embry 1977; Jones 1974; Walters 1976.

13. ARCEUTHOBIUM OCCIDENTALE - Digger pine dwarf mistletoe.

PRINCIPAL HOSTS: Pinus sabiniana, P. radiata, P. muricata.

DISTRIBUTION: U.S.: California.

DAMAGE: California Forest Pest Control Action Council 1968; Hawksworth 1969; Offord 1960; Peirce 1905; Roy 1966.

CONTROL: Kimmey 1957b.

14. ARCEUTHOBIUM PUSILLUM - Eastern dwarf mistletoe.

PRINCIPAL HOSTS: Picea mariana, P. glauca.

DISTRIBUTION: CANADA: Manitoba, New Brunswick, Newfoundland, Nova Scotia, Ontario, Prince Edward Island, Quebec, Saskatchewan. U.S.: Connecticut, Maine, Massachusetts, Michigan, Minnesota, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and Wisconsin.

DAMAGE: Anderson 1949; Anderson and Kaufert 1959; Anderson and Moser 1977; Brower 1960; Doerner 1975; Ostry and Nicholls 1976; Pomerleau 1942.

CONTROL: Anderson 1949; Anderson and Kaufert 1953; Doerner 1975; French and others 1968; Johnston 1977; LeBarron 1948; Nash 1955.

15. ARCEUTHOBIUM TSUGENSE - Hemlock dwarf mistletoe.

PRINCIPAL HOSTS: Tsuga heterophylla, T. mertensiana.

DISTRIBUTION: CANADA: British Columbia, U.S.: Alaska, California, Oregon, and Washington.

DAMAGE: Baranyay and Smith 1972; Etheridge 1973; Hunt 1971; Kingsley 1977; Shea and Stewart 1972; Smith 1969; Sterling 1962; Wellwood 1956.

CONTROL: Baranyay and Smith 1972; Buckland and Marples 1952; Driver 1975; Graham 1967; Kimmey 1957b; Kingsley 1977; Russell 1966, 1971; Shea 1966; Shea and Stewart 1972; Smith and Baranyay 1970; Sterling 1962; Stewart 1976.

16. ARCEUTHOBIUM VAGINATUM subsp. CRYPTOPODUM - Southwestern dwarf mistletoe.

PRINCIPAL HOSTS: Pinus ponderosa var. scopulorum, P. ponderosa var. arizonica, P. engelmannii.

DISTRIBUTION: U.S.: Arizona, Colorado, New Mexico, Texas, and Utah.

DAMAGE: Andrews and Daniels 1960; Edminster and Hawksworth 1976; Gill 1954; Gill and Hawksworth 1954; Gottfried and Embry 1977; Hawksworth 1961; Hawksworth and Lusher 1956; Kortian and Long 1922; Lightle 1966; Lightle and Hawksworth 1973; Lightle and Weiss 1974; Myers and others 1976; Pearson 1950.

CONTROL: Edminster and Hawksworth 1976; Gill 1954; Gill and Hawksworth 1954; Hawksworth 1961; Hawksworth and Andrew 1961; Hawksworth and others 1968; Heidmann 1968; Lightle and others 1967; Lightle and Hawksworth 1973; Lightle and Weiss 1974; Mark and Hawksworth 1974; Myers and others 1976; Pearson 1950; Schubert 1974; Walters 1978.

LITERATURE CITED

Acciavatti, Robert E, and Melvyn J. Weiss. 1974. Evaluation of dwarf mistletoe on Engelmann spruce, Fort Apache Indian Reservation, Arizona. Plant Dis. Rep. 58:418-419.

Aho, Paul, and Jim Hadfield. 1975. How to estimate defect in white fir in south-central Oregon. U.S. For. Serv., Pacific Northwest For. and Range Exp. Stn., Unnumbered Publ., 10 p.

Alexander, N.E., J. H. Borden, and J. M. Vakenti. 1976. A pest management study of a mountain pine beetle outbreak in tree farm license Number 9. Simon Fraser Univ., B.C., Pest Manage. Pap. No. 8, 109 p.

Alexander, Robert R. 1974. Silviculture of subalpine forests in the central and southern Rocky Mountains: The status of our knowledge. USDA For. Serv. Res. Pap. RM-121, 88 p.

Alexander, Robert R. 1975. Partial cutting in old-growth lodgepole pine. USDA For. Serv. Res. Pap. RM-136, 17 p., Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Anderson, Ralph L. 1949. The black spruce dwarf mistletoe in Minnesota. MS thesis, Univ. of Minn., St. Paul, Minn., 139 p.

Anderson, Ralph L., and F. H. Kaufert. 1953. The control of dwarf mistletoe on black spruce. Univ. Minnesota For. Notes 13:1-2.

Anderson, Ralph L., and F. H. Kaufert. 1959. Brooming response of black spruce to dwarfmistletoe infection. For. Sci. 5:356-364.

Anderson, Robert L., and D. G. Mosher. 1977. Occurrence of eastern dwarf mistletoe on black spruce in six national forests in the Lake states. USDA For. Serv. Northeast Area, For. Insect and Dis. Manage. Rep. S-1-77, 8 p.

Andrews, Stuart R., and John P. Daniels. 1960. A survey of dwarfmistletoes in Arizona and New Mexico. U.S. Dep. Agric., For. Serv., Rocky Mt. For. and Range Exp. Stn. Stn. Pap. 49, 17 p.

Baranyay, J. A. 1970. Lodgepole pine dwarf mistletoe in Alberta. Can. Dep. Fish. and For., For. Serv. Publ. 1286, 22 p.

Baranyay, J. A. 1975. Dwarf mistletoe as a factor in the management of lodgepole pine forests in Western Canada. Manage. of Lodgepole Pine Ecosystems, Symp. Proceed., Wash. State Univ., D. A. Baumgartner (ed.), Vol. 1:359-367.

Baranyay, J. A., and L. Safranyik. 1970. Effect of dwarf mistletoe on growth and mortality of lodgepole pine stands in Alberta. Can. Dep. Fish. and For., For. Serv. Publ. 1285, 19 p.

Baranyay, J. A., and R. B. Smith. 1972. Dwarf mistletoes in British Columbia and recommendations for their control. Can. For. Serv. Rep. BC-X-72, 18 p.

Barrett, James W. 1973. Northwestern ponderosa pine. In Silvicultural systems for the major forest types of the United States. U.S. Dep. Agric., Agric. Handb. 445, p. 17-19.

Boe, K. M. 1958. Silvics of western larch. U.S. Dep. Agric., For. Serv. Intermt. For. and Range Exp. Stn. Misc. Publ. 16, 17 p.

Brower, A. E. 1960. Dwarf mistletoe in Maine. Maine Field Nat. 16(2):35-38.

Brown, Donald H. 1977. Management guidelines for lodgepole pine stands infected with comandra blister rust and dwarf mistletoe. USDA For. Serv., Rocky Mt. Reg., For. Insect and Dis. Manage. Tech. Rep. R2-9, 21 p.

Buckland, D. C., and E. G. Marples. 1952. Management of western hemlock infested with dwarf mistletoe. British Columbia Lumberman 36(5):50-51, 136, 138, 140.

Byler, James W. 1975. Pest damage inventory. Proc. 22nd West. Int. For. Dis. Work Conf., 1975: 30-34.

California Forest Pest Control Action Council. 1968. Forest pest conditions in California - 1967. Calif. Div. Forest., Sacramento, Calif. 24 p.

Chick, W. F. 1936. Line transect survey, season of 1935, Bryce Canyon National Park. U.S. Dep. Interior, Natl. Park Serv. Rep., 40 p.

Childs, T. W.
1963. Dwarfmistletoe control opportunities in ponderosa pine reproduction. Pacific Northwest For. and Range Exp. Stn., Portland, Oreg., 19 p.

Childs, T. W., and J. W. Edgren.
1967. Dwarfmistletoe effects on ponderosa pine growth and trunk form. For. Sci. 13:167-174.

Childs, T. W., and Earle R. Wilcox.
1966. Dwarfmistletoe effects in mature ponderosa pine forests in south-central Oregon. J. For. 64:246-250.

Craig, G. A., and W. P. Maguire.
1949. The California pine region forest handbook. Calif. State Board For. 193 p.

Dobie, J., and A. A. Britneff.
1975. Lumber grades and volumes from lodgepole pine infected with dwarf mistletoe. Wood and Fiber 7:104-109.

Doerner, R. G.
1975. Northeastern States (R-9). In Forest insect and disease conditions in the United States - 1973. p. 46-51. U.S. Dep. Agric., For. Serv., Washington, D.C.

Dooling, Oscar J.
1971. Dwarf mistletoe in the Northern Region. USDA For. Serv., Northern Reg., Div. of State and Private For. Insect and Dis. Rep. 15 p., Missoula, Mont.

Dooling, Oscar J.
1974. Dwarf mistletoe control...why and what? USDA For. Serv., Northern Reg., For. Environ. Prot. Rep. 74-16, Missoula, Mont. 11 p.

Driver, Charles H.
1975. (R_X) Prescription for protective management in hemlock. West. For. and Conserv. Assoc. Perm. Assoc. Committees Proc., p. 143-145.

Dunning, Duncan.
1923. Some results of cutting in the Sierra forests of California. U.S. Dep. Agric. Bull. 1176, 27 p.

Edminster, Carleton B., and Frank G. Hawksworth.
1976. User's guide to SWYLD2: Yield tables for even-aged and two-storied stands of southwestern ponderosa pine, including effects of dwarf mistletoe. USDA For. Serv. Gen. Tech. Rep. RM-23, 8 p., Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Etheridge, D. E.
1973. Wound parasites causing tree decay in British Columbia. Can. Dep. Environ. For. Serv., Pacific For. Res. Cent. For. Pest Leafl. 62, 15 p.

Flora, Donald F.
1966a. Economic guides for ponderosa pine dwarfmistletoe control in young stands of the Pacific Northwest. U.S. For. Serv. Res. Pap. PNW-29, 16 p. Pacific Northwest For. and Range Exp. Stn., Portland, Oreg.

Flora, Donald F.
1966b. A method of forecasting returns from ponderosa pine dwarf mistletoe control. U.S. For. Serv. Res. Pap. PNW-132, 17 p. Pacific Northwest For. and Range Exp. Stn., Portland, Oreg.

Fowells, H. A., and G. H. Schubert.
1956a. Seed crops of forest trees in the pine region of California. U. S. Dep. Agric. Tech. Bull. 1150, 48 p.

Fowells, H. A., and G. H. Schubert.
1956b. Silvical characteristics of sugar pine. U. S. Dep. Agric., For. Serv. Calif. For. and Range Exp. Stn. Tech. Pap. 14, 19 p.

French, D. W., M. P. Meyer, and R. L. Anderson.
1968. Control of dwarfmistletoe on black spruce. J. For. 66:359-360.

Gill, L. S.
1954. Dwarfmistletoe of ponderosa pine in the Southwest. U. S. Dep. Agric., For. Serv., Rocky Mt. For. and Range Exp. Stn., Stn. Pap. 14, 9 p.

Gill, L. S., and F. G. Hawksworth.
1954. Dwarfmistletoe control in Southwestern ponderosa pine forests under management. J. For. 52(5):347-353.

Gill, L. S., and F. G. Hawksworth.
1964. Dwarfmistletoe of lodgepole pine. U.S. Dep. Agric., For. Pest Leafl. 18, 7 p.

Gillman, Linnea S., and Wilmer F. Bailey.
1977. Forest insect and disease management annual report, Rocky Mountain Region, 1976. USDA For. Serv., Rocky Mt. Reg., For. Insect and Dis. Manage. 56 p.

Goodding, L. N.
1938. Notes on native and exotic plants of Region 8 with special reference to their value in the soil conservation program. U.S. Dep. Agric., Soil Conserv. Serv. 152 p.

Gordon, Donald T.
1973a. Damage from wind and other causes in mixed white fir-red fir stands adjacent to clearcuttings. USDA For. Serv. Res. Pap. PSW-90, 22 p., Pacific Southwest For. and Range Exp. Stn., Berkeley, Calif.

Gordon, Donald T.
1973b. Released advance reproduction of white and red fir...growth, damage, mortality. USDA For. Serv. Res. Pap. PSW-95, 12 p., Pacific Southwest For. and Range Exp. Stn., Berkeley, Calif.

Gordon, Donald T., and Douglass F. Roy.
1973. Red fir-white fir. In Silvicultural systems for the major forest types of the United States. U.S. Dep. Agric., Agric. Handb. 445, 124 p.

Gottfried, Gerald J., and Robert S. Embry.
1977. Distribution of Douglas-fir and ponderosa pine dwarf mistletoe in a virgin Arizona mixed conifer stand. USDA For. Serv. Res. Pap. RM-192, 16 p., Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Graham, Donald P.
1960. Surveys expose dwarfmistletoes problem in Inland Empire. West. Conserv. J. 17 (1):56-58.

Graham, Donald P.
1961. Dwarfmistletoes of Douglas-fir. U.S. Dep. Agric., For. Pest Leafl. 54, 4 p.

Graham, Donald P.
1964. Dwarfmistletoe survey in western Montana. U.S. For. Serv. Res. Note INT-14, 7 p., Intermt. For. and Range Exp. Stn., Ogden, Utah.

Graham, Donald P.
1967. A training aid on dwarfmistletoe and its control. U.S. For. Serv., Pacific Northwest Region, Misc. Publ., Portland, Oreg.

Haglund, Stephen A., and Oscar J. Dooling.
1972. Observations on the impact of dwarf mistletoe on Douglas-fir in western Montana. USDA For. Serv., Insect and Dis. Rep. D-72-1, Northern Region, Missoula, Mont. 6 p.

Hallin, W. E.
1957. Silvical characteristics of red fir and shasta red fir. U.S. Dep. Agric., For. Serv., Calif. For. and Range Exp. Stn., Tech. Pap. 16, Berkeley, Calif., 8 p.

Hallin, William E.
1959. The application of unit area control in the management of ponderosa-Jeffrey pine at Blacks Mountain Experimental Forest. U.S. Dep. Agric. Tech. Bull. 1191, 96 p.

Hart, Dennis R., and Charles H. Driver.
1970. Protection aspects of western hemlock. Univ. of Washington, Coll. of For. Resour. Institute of For. Prod., For. Res. Monogr. 10, 121 p.

Hawksworth, F. G.
1958. Survey of lodgepole pine dwarfmistletoe on the Roosevelt, Medicine Bow, and Bighorn National Forests. U.S. Dep. Agric., Rocky Mt. For. and Range Exp. Stn., Stn. Pap. 35, 13 p.

Hawksworth, F. G.
1961. Dwarfmistletoe of ponderosa pine in the Southwest. U.S. Dep. Agric. Tech. Bull. 1246, 112 p.

Hawksworth, Frank G.
1969. Rapid intensification and upward spread of dwarf mistletoe in inoculated digger pines. Plant Dis. Rep. 53(8):615-617.

Hawksworth, F. G., and S. R. Andrews.
1961. Guides for pruning dwarfmistletoe-infected ponderosa pine branches. U.S. Dep. Agric., For. Serv., Rocky Mt. For. and Range Exp. Stn. Res. Note 64, 3 p., Fort Collins, Colo.

Hawksworth, F. G., and D. P. Graham.
1963. Dwarfmistletoes on spruce in the Western United States. Northwest Sci. 37:31-38.

Hawksworth, F. G., and T. E. Hinds.
1964. Effects of dwarfmistletoe on immature lodgepole pine stands in Colorado. J. For. 62:27-32.

Hawksworth, F. G., and N. E. Johnson.
1961. Guides for pruning dwarfmistletoe infected lodgepole pine branches. U.S. Dep. Agric., For. Serv., Rocky Mt. For. and Range Exp. Stn., Res. Note 65, 3 p.

Hawksworth, F. G., and A. A. Lusher.
1956. Dwarfmistletoe survey and control on the Mescalero Apache Reservation, New Mexico. J. For. 54:384-390.

Hawksworth, F. G., J. L. Stewart, and W. F. Bailey.
1968. You can save your pines from dwarf mistletoe. U. S. For. Serv. Res. Pap. RM-35, 20 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Hawksworth, F. G., and D. Wiens.
1972. Biology and classification of dwarf mistletoes (Arceuthobium). U.S. Dep. Agric., Agric. Handb. 401, 234 p.

Hawksworth, F. G., T. E. Hinds, D. W. Johnson, and T. D. Landis.
1977. Silvicultural control of dwarf mistletoe in young lodgepole pine stands. USDA For. Serv., Rocky Mt. Region, For. Insect and Dis. Manage., Tech. Rep. R2-10, 12 p.

Heidmann, L. J.
1968. Silvicultural control of dwarf mistletoe in heavily infected stands of ponderosa pine in the Southwest. U.S. For. Serv. Res. Pap. RM-36, 11 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Hopkins, H. G.
1959. Salvaging mistletoe-damaged timber. Proc. 49th Western For. Conf. 1958:36-39, San Francisco, Calif., West. For. and Conserv. Assoc., Portland, Oreg.

Hreha, Alyce M.
1978. A comparative distribution of two mistletoes: Arceuthobium divaricatum and Phoradendron juniperinum (South Rim, Grand Canyon National Park, Arizona). MS thesis, Brigham Young Univ., Provo, Utah, 62 p.

Hunt, K.
1971. A comparison of Kraft pulping of sound and dwarf mistletoe-infected western hemlock wood. Can. Dep. Fish. and For., For. Prod. Lab., Vancouver, Inf. Rep. VP-X-78, 7 p., Vancouver, B.C.

Hutchison, S. B., and A. L. Roe.
1962. Management for commercial timber, Clark Fork Unit, Montana. U.S. Dep. Agric., For. Serv. Intermt. For. and Range Exp. Stn. Res. Pap. 65, 32 p.

Johnston, William F.
1977. Manager's handbook for black spruce in the north-central states. USDA For. Serv. Gen. Tech. Rep. NC-34, 18 p. North-central For. Exp. Stn., St. Paul, Minn.

Jones, John R.
1974. Silviculture of southwestern mixed conifers and aspen: The status of our knowledge. USDA For. Serv. Res. Pap. RM-122, 44 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Kimmey, J. W.
1957a. Application of indicator cull factors to white and red fir stands in the Sierra Nevada. U.S. Dep. Agric., For. Serv., Calif. For. and Range Exp. Stn. For. Res. Note 127, 5 p. Berkeley, Calif.

Kimmey, J. W.
1957b. Dwarfmistletoes of California and their control. U.S. Dep. Agric., For. Serv., Calif. For. and Range Exp. Stn., Tech. Pap. 19, 12 p. Berkeley, Calif.

Kimmey, James W., and Donald P. Graham
1960. Dwarfmistletoes of the Intermountain and northern Rocky Mountain regions and suggestions for control. U.S. Dep. Agric., For. Serv., Intermt. For. and Range Exp. Stn., Stn. Res. Pap. 60, 19 p.

Kimmey, J. W., and H. H. Bynum.
1961. Heart rots of red and white firs. U.S. Dep. Agric., For. Pest Leafl. 52, 4. p.

Kimmey, J. W., and J. L. Mielke.
1959. Western dwarfmistletoe on ponderosa pine. U.S. Dep. Agric., For. Pest Leafl. 40, 7 p.

Kingsley, Duane.
1977. Management of conifer stands infected with dwarf mistletoe in southwest Oregon. Proc. 24th Western Internatl. For. Dis. Work Conf., 1976:51-54, Victoria, B.C.

Korstian, C. F., and W. H. Long.
1922. The western yellow pine mistletoe: Effect on growth and suggestions for control. U. S. Dep. Agric. Bull. 1112, 35 p.

Landis, T., R. Averill, and R. Frye.
1977. Central rocky mountains (R-2). In Forest Insect and Disease Conditions in the United States, 1974. p.28-32. U.S. Dep. Agric., For. Serv., Washington, D.C.

LeBarron, Russel K.
1948. Silvicultural management of black spruce in Minnesota. U.S. Dep. Agric., Circ. 791, 60 p.

LeBarron, R. K.
1952. Silvicultural practices for lodgepole pine in Montana. U.S. Dep. Agric., For. Serv. North. Rocky Mt. For. and Range Exp. Stn., Stn. Pap. 33, 19 p.

Lightle, Paul C.
1966. Dwarf mistletoe reduces basal area growth in ponderosa pine in the Southwest (Abstr.). Phytopathology 56:886-887.

Lightle, P. C., S. R. Andrews, and W. E. Mouser
1967. Recleaning the dwarfmistletoe control area on the Mescalero Apache Reservation, New Mexico. J. For. 65(11):816-817.

Lightle, Paul C., and Frank G. Hawksworth.
1973. Control of dwarf mistletoe in a heavily used ponderosa pine recreation forest: Grand Canyon, Arizona. USDA For. Serv. Res. Pap. RM-106, 22 p., Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Lightle, Paul C., and Melvyn J. Weiss.
1974. Dwarf mistletoe of ponderosa pine in the Southwest. U. S. Dep. Agric. For. Pest Leafl. 19 (Rev.), 8 p.

Loomis, Robert C.
1972. Disease detection survey. Air Pollution, Coronado National Forest, Arizona. USDA For. Serv. Southwest. Reg., For. Insect and Dis. Manage. Br., 12 p.

Lotan, J. E., and R. R. Alexander.
1973. Lodgepole pine. In Silvicultural systems for the major forest types of the United States, p. 42-44. U.S. Dep. Agric., Handb. 445.

McGregor, M. D., and R. E. Williams.
1974. Forest insect and disease conditions. Northern Region. USDA For. Serv., North. Reg., Div. State and Priv. For. Rep. 74-1, 24 p.

Mark, Walter R., and Frank G. Hawksworth.
1974. How important are bole infections in spread of ponderosa pine dwarf mistletoe? J. For. 72:146-147.

Mathiasen, Robert L.
1977. The taxonomy and epidemiology of dwarf mistletoes parasitizing white pines in Arizona. Ph.D. thesis, Univ., of Ariz., Tucson, Ariz.

Muir, J. A.
1965. Dwarf mistletoe, Arceuthobium americanum Nutt. ex Engelm. (c). Parasitic effects and reproductive ability of dwarf mistletoe. Can. Dep. For., For. Entomol. & Pathol. Br. Ann. Rep. 1965:130-131.

Munns, E. N.
1919. Effect of fertilization on the seed of Jeffrey pine. Plant World 22:138-144.

Myers, Clifford A., Carleton B. Edminster, and Frank G. Hawksworth.
1976. SWYLD2:Yield tables for even-aged and two-storied stands of southwestern ponderosa pine, including effects of dwarf mistletoe. USDA For. Serv. Res. Pap. RM-163, 25 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Myers, Clifford A., Frank G. Hawksworth, and James L. Stewart.
1971. Simulating yields of managed, dwarf mistletoe-infested lodgepole pine stands. USDA For. Serv., Res. Pap. RM-72, 15 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Nash, R. W.
1955. Dwarf or false mistletoe (Arceuthobium pusillum Peck). Maine Forest. Comm., Bienn. Rep. 30 (1953-1954):126-127.

Offord, H.
1960. Pest conditions in California - 1959. In Western For. Pest Conditions 1959. p. 12-13. Western Forest and Conserv. Assoc., Portland, Oreg.

Offord. H. R.
1961. Forest diseases in California. Problems and research program of the Pacific Southwest Station. U.S. Dep. Agric., For. Serv., Pacific Southwest For. and Range Exp. Stn., Tech. Pap. 60, 29 p.

On, D., and O. J. Dooling.
1969. A study of the effect of dwarf mistletoe infection on the growth of western larch. U.S. For. Serv., Div. of Timber Manage. and State and Priv. Forest., Northern Reg. (Unpubl.), Missoula, Mont. 7 p.

Ostry, M. E., and T. H. Nicholls.
1976. How to identify eastern dwarf mistletoe on black spruce. USDA For. Serv. North Cent. Exp. Stn., St. Paul, Minn., 5 p.

Parmeter, J. R., Jr., and R. F. Scharpf.
1963. Dwarfmistletoe on red fir and white fir in California. J. For. 61:371-374.

Parmeter, J. R., Jr., and R. F. Scharpf.
1972. Spread of dwarf mistletoe from discrete seed sources into young stands of ponderosa and Jeffrey pines. USDA, For. Serv. Res. Note PSW-269, 5 p. Pacific Southwest For. and Range Exp. Stn., Berkeley, Calif.

Pearson, G.A.
1950. Management of ponderosa pine in the Southwest. U.S. Dep. Agric., For. Serv. Agric. Monogr. 6, 218 p.

Peirce, G. J.
1905. The dissemination and germination of Arceuthobium occidentale Eng. Ann. Bot. 19:99-113.

Pierce, William R.
1960. Dwarf mistletoe and its effect upon the larch and Douglas fir of western Montana. Montana State Univ., Sch. of For. Bull. 10, 38 p. Missoula, Mont.

Piirto, Douglas D., Donald L. Crews, and Harry E. Troxell.
1974. The effects of dwarf mistletoe on the wood properties of lodgepole pine. Wood and Fiber 6:26-35.

Pomerleau, R.
1942. Le gui de l' epinnette noire dans le Quebec. Natur. Can. 69:11-31.

Pong, W. Y., and G. H. Jackson.
1971. Diagramming surface characteristics of true fir logs. Supplement to log diagramming guide for western softwoods. USDA For. Serv., Pacific Northwest For. and Range Exp. Stn., Portland, Oreg.

Roe, Arthur L., and Gene D. Amman.
1970. The mountain pine beetle in lodgepole pine forests. USDA For. Serv. Res. Pap. INT-71, 23 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Roth, L. F.
1953. Pine dwarfmistletoe on the Pringle Falls Experimental Forest. U.S. Dep. Agric. For. Serv., Pacific Northwest For. and Range Exp. Stn., Res. Note 91, 3 p. Portland, Oreg.

Roth, L. F.
1971. Dwarf mistletoe damage to small ponderosa pines. For. Sci. 17:373-380.

Roy, Douglass F.
1966. Silvical characteristics of Monterey pine (Pinus radiata [D. Don]). U.S. For. Serv. Res. Pap. PSW-31, 21 p. Pacific Southwest For. and Range Exp. Stn., Berkeley, Calif.

Russell, K. W.
1966. Dwarfmistletoe control in state parks. Washington State Dep. Nat. Res., For. Land Manage. Bull. 3, 10 p.

Russell, Kenelm W.
1971. Precommercial thinning in dwarfmistletoe control. In Precommercial thinning of coastal and intermountain forests in the Pacific Northwest. Symp. Proc., D. M. Baumgartner, (ed.), p. 23-40, Wash. State Univ., Pullman, Wash.

Scharpf, Robert F.
1964. Dwarfmistletoe on true firs in California. U.S. Dep. Agric., For. Pest Leafl. 89, 7 p.

Scharpf, Robert F.
1969a. Dwarf mistletoe on red fir...infection and control in understory stands. U.S. For. Serv. Res. Pap. PSW-50, 8 p. Pacific Southwest For. and Range Exp. Stn., Berkeley, Calif.

Scharpf, Robert F.
1969b. Cytospora abietis associated with dwarf mistletoe on true firs in California. Phytopathology 59:1657-1658.

Scharpf, Robert F.
1977. Dwarf mistletoe does not increase trunk taper in released red firs in California. USDA For. Serv. Res. Note PSW-326, 3 p. Pacific Southwest For. and Range Exp. Stn., Berkeley, Calif.

Scharpf, Robert F., and H. H. Bynum.
1975. Cytospora canker of true firs. U.S. Dep. Agric. For. Pest Leafl. 146, 5 p.

Scharpf, Robert F., and F. G. Hawksworth.
1968. Dwarf mistletoe on sugar pine. U.S. Dep. Agric. For. Pest Leafl. 113, 4 p.

Scharpf, Robert F., Frank G. Hawksworth, and Bernard J. Erickson.
1976. Mistletoe literature of the world: A user's guide to a FAMULUS retrieval system. USDA For. Serv. Gen. Tech. Rep. RM-30, 5 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Scharpf, R. F., and J. R. Parmeter, Jr.
1967. The biology and pathology of dwarfmistletoe Arceuthobium campylopodum f. abietinum, parasitizing true firs (Abies spp.) in California. U.S. Dep. Agric., Tech. Bull. 1362, 42 p.

Schubert, Gilbert H.
1974. Silviculture of southwestern ponderosa pine: The status of our knowledge. USDA For. Serv. Res. Pap. RM-123, 71 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Schwandt, John W.
1977. Dwarf mistletoe control guidelines for Idaho forests. Idaho Div. For. Res., Bur. Priv. For., For. Insect and Dis. Control Rep. 77-2, 13 p.

Shea, Keith R.
1960. Dwarfmistletoe of Douglas-fir in Oregon and Washington. Weyerhaeuser Co., For. Dep. Bull. 4 p., Feb. 1960.

Shea, Keith R.
1963. Marking guide evolved for mistletoe-hit Douglas fir. For. Indus. 90(1):58-59, Jan. 1963.

Shea, Keith R.
1964a. Diameter increment of ponderosa pine infected with dwarfmistletoe in south-central Oregon. J. For. 62:743-748.

Shea, K. R.
1964b. Silvicultural control of ponderosa pine dwarfmistletoe in south-central Oregon - A five-year study. J. For. 62:871-875.

Shea, Keith R.
1966. Dwarfmistletoe of coastal western hemlock: principles and practices for control. Weyerhaeuser For. Pap. No. 9, 14 p.

Shea, Keith R.,and Peter G. Belluschi.
1965. Effects of dwarfmistletoe on diameter increment of immature ponderosa pine before and after partial logging. Weyerhaeuser For. Pap. 4, 7 p.

Shea, Keith R., and David K. Lewis.
1971. Occurrence of dwarf mistletoe in sanitized ponderosa pine in south-central Oregon. Northwest Sci. 45:94:99.

Shea, K. R., and J. L. Stewart.
1972. Hemlock dwarf mistletoe. U.S. Dep. Agric. For. Pest Leafl. 135, 6 p.

Smith, R. B.
1969. Assessing dwarf mistletoe on western hemlock. For. Sci. 15:277-285.

Smith, R. B., and J. A. Baranyay.
1970. Dwarf mistletoe in British Columbia. Can. Dep. Fisheries and Forest., Victoria For. Serv., Victoria, B. C.

Sterling, R. T.
1962. Dwarfmistletoes parasite of western hemlock. Proc. Fifth World For. Congr., Seattle, Wash., 1960, Vol. II:893-896.

Stewart, James L.
1976. Dwarf mistletoe infection from residual hemlock on cutover stands. USDA For. Serv. Res. Note PNW-278, 3 p. Pacific Northwest For. and Range Exp. Stn., Portland, Oreg.

Strand, M. A., and L F. Roth.
1976. Simulation model for spread and intensification of western dwarf mistletoe in thinned stands of ponderosa pine saplings. Phytopathology 66:888-895.

Struble, G. R.
1942. Crown decadence of sugar pine in relation to attacks by the mountain pine beetle. Prelim. Rep. U.S. Dep. Agric., Bur. Entomol. and Plant Quarantine, For. Ins. Lab., Berkeley, Calif. [Unpubl.]

Struble, G. R.
1965. Attack pattern of mountain pine beetle in sugar pine stands. U.S. For. Serv. Res. Note PSW-60, 7 p. Pacific Southwest For. and Range Exp. Stn., Berkeley, Calif.

Urban, Karl A.
1968. An ecological appraisal of the dwarfmistletoe problem at Craters of the Moon National Monument, Idaho. M.S. thesis, 89 p., Univ. Idaho, Moscow, Idaho.

Wagener, Willis W.
1961. Forty years of dwarfmistletoe on a ponderosa pine plot near Quincy, California. U.S. Dep. Agric., For. Serv., Pacific Southwest For. and Range Exp. Stn., Berkeley, Calif.

Wagener, Willis W.
1965. Dwarfmistletoe removal and reinvasion in Jeffrey and ponderosa pine, northeastern California. U.S. For. Serv. Res. Note PSW-73, 8 p., Pacific Southwest For. and Range Exp. Stn., Berkeley, Calif.

Walters, James W.
1976. A guide to mistletoes of Arizona and New Mexico. USDA For. Serv., Southwest Reg., For. Insect and Dis. Manage., 7 p. Albuquerque, N. Mex.

Walters, James W.
1978. Simulated yield tables for dwarf mistletoe management in ponderosa pine stands (SWYLD2 Program), Phase I. Two-storied stands, 1977. USDA For. Serv., Southwestern Reg., For. Insect and Dis. Manage. Tech. Rep., R-3 78-7, 22 p. Albuquerque, N. Mex.

Weir, James R.
1916a. Mistletoe injury to conifers in the Northwest. U.S. Dep. Agric. Bull. 360, 39 p.

Weir, James R.
1916b. Larch mistletoe: some economic considerations of its injurious effects. U. S. Dep. Agric. Bull. 317, 25 p.

Weir, James R.
1918. Effects of mistletoe on young conifers. J. Agric. Res. 12(11):715-718.

Weir, L. C.
1977. Dwarf mistletoes in Oregon. Oregon State For. Dep., For. Insect and Dis. Notes. 25 p.

Wellner, Charles A., and Russell A. Ryker.
1973. Ponderosa pine and Rocky Mountain Douglas-fir. In Silvicultural systems for the major forest types of the United States. U.S. Dep. Agric., Agric. Handb. 445, p. 35-37.

Wellwood, R. W.
1956. Some effects of dwarf mistletoe on hemlock. For. Chronicle 32(3):282-296, Sept. 1956.

Wilcox, W. Wayne, W. Y. Pong, and J. R. Parmeter.
1973. Effects of mistletoe and other defects on lumber quality in white fir. Wood and Fiber 4:272-277.

Williams, Wayne T., Freida Fortier, and John Osborn.
1972. Distribution of three species of dwarf mistletoe on their principal pine hosts in the Colorado Front Range. Plant Dis. Rep. 56:223-227.

Wright, Ernest.
1942. Cytospora abietis, the cause of a canker of true firs in California and Nevada. J. Agric. Res. 65:143-153.

Ziegler, Robert S.
1978. The vegetation dynamics of Pinus contorta forest, Crater Lake National Park, Oregon. M.S. thesis, Oregon State Univ., Corvallis, Oreg. [Unpubl.]

OPERATIONAL FOREST MANAGEMENT PLANNING METHODS:

proceedings, meeting of Steering Systems Project Group, International Union of Forestry Research Organizations

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OPERATIONAL FOREST MANAGEMENT PLANNING METHODS:

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PREFACE

At the XVIth World Congress held in Oslo, Norway, in 1976, the International Union of Forestry Research Organizations (IUFRO) reaffirmed its commitment to study forestry problems in the developing countries and to seek solutions. This collection of papers is the contribution to this task made by the Steering Systems Project Group, Division IV. This project was established at the Congress at the suggestion of Hans Speidel, Richard Plochman, and Robert Magin, to promote communication and collaboration among IUFRO scientists doing research in the development and application of forest management planning methods. The Project Group is conducting two major activities. First, an International Directory of Computerized Planning and Research Tools is being established under the sponsorship of the Forest Service, U.S. Department of Agriculture. Second, international meetings are held to inform members of the state of the art in forest management planning, and to promote the collaboration of all forestry researchers in addressing the challenges posed by forest management in developing nations.

The 14 papers collected here report on planning methods which have been successfully used in developed countries and which—in the judgment of the members of the Project Group—may be useful in attacking problems in less developed nations. Many of our members are deeply aware of their limited grasp of these problems. Our sincere hope is the these papers will open a dialogue which will lead to better understanding of these problems and to an effective collaboration among researchers from all nations in an attack on these problems.

The papers presented here span the spectrum of approaches used in forest management planning in recent decades. In the first paper, Bohumil Dolezal presents the classical approach to planning intensive forest management and establishes the validity of these principles for dealing with contemporary problems of developing economies.

The remaining papers deal with specific planning techniques, all of which—except two—require the use of electronic computers to conduct simulations, solve mathematical programs, or invert input-output matrices. The papers by Denie Gerold and Allen Lundgren demonstrate the usefulness, efficiency, modest cost, and versatility of electronic computers in modeling the behavior of forest stands, and in providing detailed estimates of outputs and of resources needed for the diverse conditions typically encountered in commercial forest lands.

The paper contributed by members of the Australian Forestry Council reports on six stand-growth and yield-simulation models which rely on functions derived from graphic analysis, nonlinear estimation, and generalized least squares. This paper also reports on two linear programming (LP) methods. The first of these provides an analysis of long-term cutting strategy for intensively managed *Pinus radiata* plantations. The second combines LP with the simulation of stand yields determination of thinnings and clear felling yield for an entire plantation.

Two additional papers report on methods integrating simulation and optimization methods. The model described by Joseph Buongiorno and Dennis Teeguarden uses simulation to estimate future growth, and to help managers select promising management alternatives, and linear programming to find an optimum combination of reforestation projects. William W. Phillips and Thomas D. Corcoran present an interactive model which uses simulation to explore alternative ''market transport possibilities,'' and linear programming for identifying optimal overall strategies.

The next five papers report on methods which rely on the use of LP and a recent extension of LP, goal programming. Ivan Kolenka presents a model for planning the logging, transport, and distribution of wood assortments in the context of a planned economy. Malcolm Kirby presents a budgeting model for large private or public forest enterprises which also provides an analytical framework for evaluation of overall management programs. The two-stage LP methods discussed in separate papers by Krishna Rustagi and Stephen Smith provide a practical strategy for dealing with one of the most vexing limitations of LP, the assumption of the availability of reliable information about future events. Richard C. Fields describes a goal programming model which provides a systematic method for dealing with a limitation of LP which has proved particularly bothersome in forestry, the impossibility of specifying an objective function which reflects adequately the incommensurable outputs of forest management.

David Betters reports on a model which integrates a computerized procedure based on factor analysis with linear programming and input-output analysis. The computerized procedure is used to develop among planners, consumers, and managers a consensus of resource use preferences. Linear programming then provides optimal combinations of forest management alternatives and an input-output model estimates the impact on local economic activity and employment levels.

The last two papers discuss systematic procedures for evaluating well-defined forest management alternatives, without paying tribute to computers. August Henne presents an operational version of Zangemeister's Nutzwertanalyse, which retains the essential features of the original scheme for ranking a set of complementary projects. Andres Weintraub reports on a heuristic procedure for selecting a management program from among mutually exclusive alternatives.

The preparation and publication of this collection of papers was made possible through the collaboration of too many persons to permit giving them individually the acknowledgement and thanks which are due them. Goran von Malmborg, co-chairman of the Steering Systems Project Group, and all our members join me in expressing special thanks to Professor Robert Magin for inviting us to meet with the Forest Management Planning and Managerial Economics Working Group and to Professor Adolf Priesol and Director George Bumbu for their warm hospitality. We also extend our special thanks to the Food and Agriculture Organization of the United Nations for allowing Dr. Arnoldo Contreras to share with us his clear understanding of forestry problems in developing countries, and for help FAO is giving us in reaching our colleagues in those countries.

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A Method of Forest Management for the Planned Introduction of Intensive Husbandry in Virgin Forest Stands

B. Dolezal

Abstract: The method proposed is derived from long experience of intensive management in forest stands of Central Europe and from our proposal for management in virgin Iranian forests of the Caspian Region. The method establishes the need for systematic planning of stand conversion to insure both sustained yield and the harvesting of sufficient timber to sustain economic development. The method also recognizes the need to integrate the planning of silvicultural activities with capital investments in roads and machinery.

INTRODUCTION

The method described in this paper is based on the realization that forest planning must be consistent with the political and economic situation of a developing country, as well as with the given natural and economic conditions, financial position, market conditions, and the technological procedures involved in the process of production, which are all traditionally taken into consideration in forest husbandry. A method of this kind is expected also to reflect the latest scientific achievements in understanding of the forest as an entity. Market conditions must be considered to insure a reasonable financial return from management. It must also be recognized that the forest is a national resource of special value in a country's watershed management and in the development of an environment beneficial to its population.

The principles discussed below and incorporated in the method for introducing an intensive system of management into virgin forest stands were obtained partly from what has been gathered during the past 250 years of intensive management in the forest stands of Central Europe, and partly from the experience gained while compiling our proposal for forest management in virgin Iranian forests of the Caspian Region. The method is based on the principles that (1) the introduction of an intensive system of management into the virgin-like forest must be planned, and (2) once converted, the commercial forest must be able to produce sustained yields adequate in quality, volume, and monetary value, and must supply the market with sufficient amounts of timber in the species and assortments needed for economic development.

The method for introducing an intensive system of management as suggested here is based on the idea of short-term credits, which are required to make the virgin stands accessible for management, for purchasing needed machinery, and if necessary, even for constructing wood-processing plants. The short-term credit needed to secure accessibility of virgin-like forests can be estimated by assuming that the stand regeneration will progress through areas that are spatially linked, so that the transport of wood from the part of the forest which has just been made accessible passes through those which have already been made accessible. The availability of short-term credit indeed appears to be an important requirement for the introduction of intensive management in the forests of developing countries.

The suggested method is based on scientific knowledge of the forest. It utilizes data on the geographical and ecological classification of forests, which serves to stratify forest land. This stratification is needed to delimit forest land planning and control units for management, to define the quantities to be estimated, and to elaborate the instructions needed to manage the forest.

METHOD

Economic Evaluation of Wood Production

Delimitation of the Forest Land Resource

It would not be reasonable to introduce intensive management into forests which, within a known period of time, are intended to serve some other type of land utilization (such as fields, meadows, grassland, dwelling estates). It is therefore urgent to determine, on the basis of consultation with competent institutions in the country, which of the forest areas will be left as permanent stands, regardless of population increases. This task appears to be urgent, especially in the territories which are characterized either by a high or by a very low forest cover percentage, compared to the targets planned for the years to come.

Survey and Analysis of Natural and Working Conditions in the Forests

The primary concerns should be the survey and analysis of soil, climate, and terrain all of which are decisive for the future productivity of the forest stands. Survey and analysis should also be concerned with the present condition of the forest stands (existing species, diameter, health condition, forest inventory data, potential production of assortments suitable for commercial and industrial uses, and the like). The remaining items to be evaluated are: conditions for management, especially the character of the topography; potential accessibility of the stands and timber transport; delimitation of gravitational areas etc.; conditions for location of timber yards and sawmills; the level of protection needed against forest fire and destructive wind.

Maps produced using photogrammetry are part of the surveys mentioned above.

Marketing

An investigation is carried out to determine the opportunities for trading timber; to assess the demand for timber assortments by local population and industries, and to estimate the export requirements as well; finally, the potential for the processing of the timber harvest by woodworking plants is assessed.

Organization of the Forest Stands

Working Circle

These are the "frames" for harvest regulation. The areas range from 15 to 50,000 ha. They are designed to insure sustained, even, and sufficient supplies of timber, in order to simplify management, and to obtain the short-term financial credits needed to make the forest accessible to transport. Working circles cover contiguous areas encompassing entire watershed or timbersheds which are homogeneous with respect to both natural and economic conditions. These working circles permit the application of a uniform method of management and a uniform type of harvesting regulation. Relatively large areas are covered by working circles. This is made possible by the introduction of the concept of "working complexes" of stands, which refer to land units homogeneous with respect to production and management. The only role left for the working circle is to insure sustained and even yields from the forest. If required, working circles can be drawn for forests managed for purposes other than timber production, e.g., protection forests, recreation forests, nature reserves, and the like.

Working Complexes of Stands

These are defined as the groupings of forest stands with ecological, productional, and management characteristics so similar that they permit the introduction of a uniform system for (1) compilation of instructions for management, (2) calculation of the index of harvest regulation, and (3) calculation of the timing of management activities for the forest, etc. The reasons for introducing the working complexes of stands into forest management are to make the goals and the decisions of management concrete, to facilitate real planning and control of managerial actions, and to simplify the managerial process. Clearly the use of working complexes is indicated when a system of intensive management is introduced into virgin-like forests.

Forest Compartments

These are defined as the permanent land management units based on the forest's biological and management typification. They range in area from 30 to 100 ha. Where possible, the forest compartments are marked off by distinct characteristics of the terrain. Their uniform morphological character should mesh with the network used for timber skidding, and with the road system. Moreover, the forest compartments are supposed to be independent units also from the point of view of forest protection. For this reason, preventive measures of protection are worked out for each compartment. Compartments are surveyed and, as a rule, their boundaries are located using photogrammetry. The forest compartments are the basic units of the forest's spatial organization, both with respect to planning and with respect to the realization of the plan.

Subcompartments

Under diversified natural and working conditions there are occasional cases when the compartment cannot cover all ecological and stand differences; it then follows that the compartment is not a convenient unit for the planning, control, and realization of pertinent measures of management in the sectors of silviculture and forest protection. Instead, subcompartments are delimited as a lower category of the forest's spatial organization. The subcompartments are assumed to possess the same properties indicated above for the compartments--those necessary for the uniform planning of management activities related to silviculture and forest protection. In this particular case, the planning of timber transport and skidding occurs within the frame of the compartment.

HARVEST REGULATION

The principle observed is that optimum productivity be reached in the forest stands within the compartment or subcompartment; at the same time, the yields produced within the frame of the working circle must be sustained and even. In compliance with the requirement for simplicity and the conditions in developing countries, harvest regulation should be based on area. It is true that allowable cuts are derived on the basis of area and volume, as well as on assortments and value, but always so that considerations for the elements of volume are subordinated to those of area.

Calculation of the Allowable Cut

The final allowable cut is determined primarily by the "normal" felling area, according to the formula:

$$e = i_n \bar{h}_u$$

where e denotes the volume of the allowable cut, i_n stands for the normal felling area, in hectares, and $\bar{h}_u$ designates the average volume per hectare of the growing stock within the working circle at the time of stand maturity.

This average stock per hectare of the working circle is obtained with the formula:

$$\bar{h}_u = \Sigma_i h_i F_i / \Sigma_i F_i$$

where h_i denotes the per-hectare stock in stands of individual working complexes, F_i indicates the area in hectares of the ith working complex belonging to the working circle, and

$$i_n = F/\bar{u}$$

where F is the area of the working circle and u is the rotation of the working circle, calculated according to the formula:

$$\bar{u} = \Sigma_i u_i F_i / \Sigma_i F_i$$

For the volume index of harvest regulation it is possible to use the final mean annual increment in stands of the working circle. This is calculated by summing up the final mean annual increments achieved in all the individual working complexes which constitute the working circle.

The stand volumes per hectare of individual working complexes are obtained by determining the growing stock volume per hectare in sample plots distributed in individual working complexes. Principles of systematic random selection must be observed to obtain representative estimates of the characteristics of the stands of the working circle.

Concerning the realization of the allowable cut: the main object of the method proposed here is to promote the harvesting of the allowable cut in a contiguous area (French terms: *quartier de regeneration*, *affectation unique*). The method thus permits respecting the silvicultural requirements of stands in individual subcompartments or compartments within the frame of the ecological and production conditions characterizing individual working complexes. In doing so, harmony is achieved between the interests of silviculture and those of cutting regulation.

For long rotations and the use of small-area harvesting sytems, the allowable cut in the *quartier de regeneration* is calculated from the formula:

$$e = \frac{H_o + Ci \cdot P/2}{P}$$

where H_o denotes the total volume of stands in the *quartier de regeneration*, P stands for the regeneration period (cutting cycle) expressed in years, and Ci designates the current increment. The number of regeneration treatments is determined with respect to the ecological requirements of the species represented in or introduced into the stands. Regeneration in the subsequent *quartier de regeneration* does not commence until completion of the stand regeneration in the *quartier de regeneration* immediately preceding.

The harvesting in stands, except for the quartiers de regeneration just under regeneration, is dependent on the possibility of transporting the material exploited. As a rule, the plan is to utilize the wood for charcoal burning, and only then carry it out of inaccessible stands on the backs of mules or donkeys. Sanitary fellings are largely concerned with the removal of sick, ill-shaped, overaged, and similar trees which if kept would not contribute to the value of the stand. The cycle for these treatments is usually fixed at 10 or 20 years; the volume of timber harvested per hectare in individual working complexes is estimated on the basis of a current survey of the condition of the stands.

SYSTEMS OF MANAGEMENT AND EXPLOITATION

The method for introducing intensive management into virgin-like forests assumes the use of a system of management and exploitation that is consistent with the natural and economic conditions of the country concerned. The main --and highly desirable--objective is to avoid the destruction of the forest's sources of production--the soil above all--due to erosion, waterlogging, or excessive growth of woody plants. The selection of the system of management is dependent also on the ecological requirements of the species in the specific stand environment, and on the technique of skidding to be employed. In general, it seems advantageous to prefer the small-area systems of management, the better to maintain the forest's production capability. This, however, should not exclude the use of regeneration cuttings when conditions are suitable.

CONCLUSIONS

In addition to what has been indicated above, the method of introducing intensive management into virgin forests assumes thorough planning to carry out the management practices effectively and to use expensive harvesting and transporting machinery efficiently. Another requirement is that all the complex aspects of forest management be taken into consideration. The same amount of attention given to the harvesting of timber must be paid to afforestation of harvested areas and to the tending and protection of new stands. The construction of a network of timber transport roads, adequately dense and duly distributed in space (about 15 km/ha), is also a prerequisite.

The method discussed in this paper is not only consistent with all the latest achievements in Central European forestry, it is also consistent with the natural, working, and politico-economic conditions found in developing countries.

Theoretical and Computational Foundations of Management Class Simulation

Denie Gerold

Abstract: Investigations on complicated, complex, and not well-ordered systems are possible only with the aid of mathematical methods and electronic data processing. Simulation as a method of operations research is particularly suitable for this purpose. Theoretical and computational foundations of management class simulation must be integrated into the planning systems of forest management and must provide a large number of alternatives for action. A model already in wide use is described.

INTRODUCTION

Research on complicated, complex, and not well-ordered systems is possible only with the aid of mathematical methods and electronic data processing equipment. With analytical model analysis (e.g. optimization models), the solution algorithm yields a specifically defined result, but computational experiments are more or less systematic test procedures for which there is no logically certain procedure for optimal solution. The purpose of the computational experiment is to search for the optimal solution or the best corresponding decision. Complete and partial searches are differentiated according to the scope of search processes within the framework of a given decision model. In complete searches all possible constellations of variables are calculated, and the optimum with respect to the objective concepts exists with certainty among the variants. The partial search is limited to a sample of all possible searches. It must be guaranteed that partial search procedures are directed toward the research goal. Partial searches differentiate between pure simulation and "design game plan." In simulation one specifically formulates definitions for actual decisions through decision rules at the beginning of a series of searches. In the design game plan, the strategies for a search series are not fixed at the beginning of the game, but develop in the course of the game as the result of chains of decisions.

Simulation is suitable as a method for operations research because of its adaptability for analysis of systems with numerous input and output quantities and complicated structures. It is distinguished by the following essential criteria:

1. A system can be simulated if it can be subdivided into a variety of elements for which the behavioral rules can be assigned.

2. The simulation encompasses a mathematical model which "runs" but is not solved; i.e., time is very important in the simulation.

3. The process of system optimization is not directly contained in the simulation.

4. The output of the modeled system is weighted in the simulation with respect to deterministic or stochastic modifications of the input.
   A number of steps must be considered in the development of a simulation model:
   (a) Formulation of goals
   (b) Formulation, weighting and comparison of possible alternatives
   (c) Selection of the best alternative with respect to the objective function (decision)
   (d) Control of the elaboration of decisions and eventual corrective measures.

The principle of the mathematical simulation is presented in figure 1.

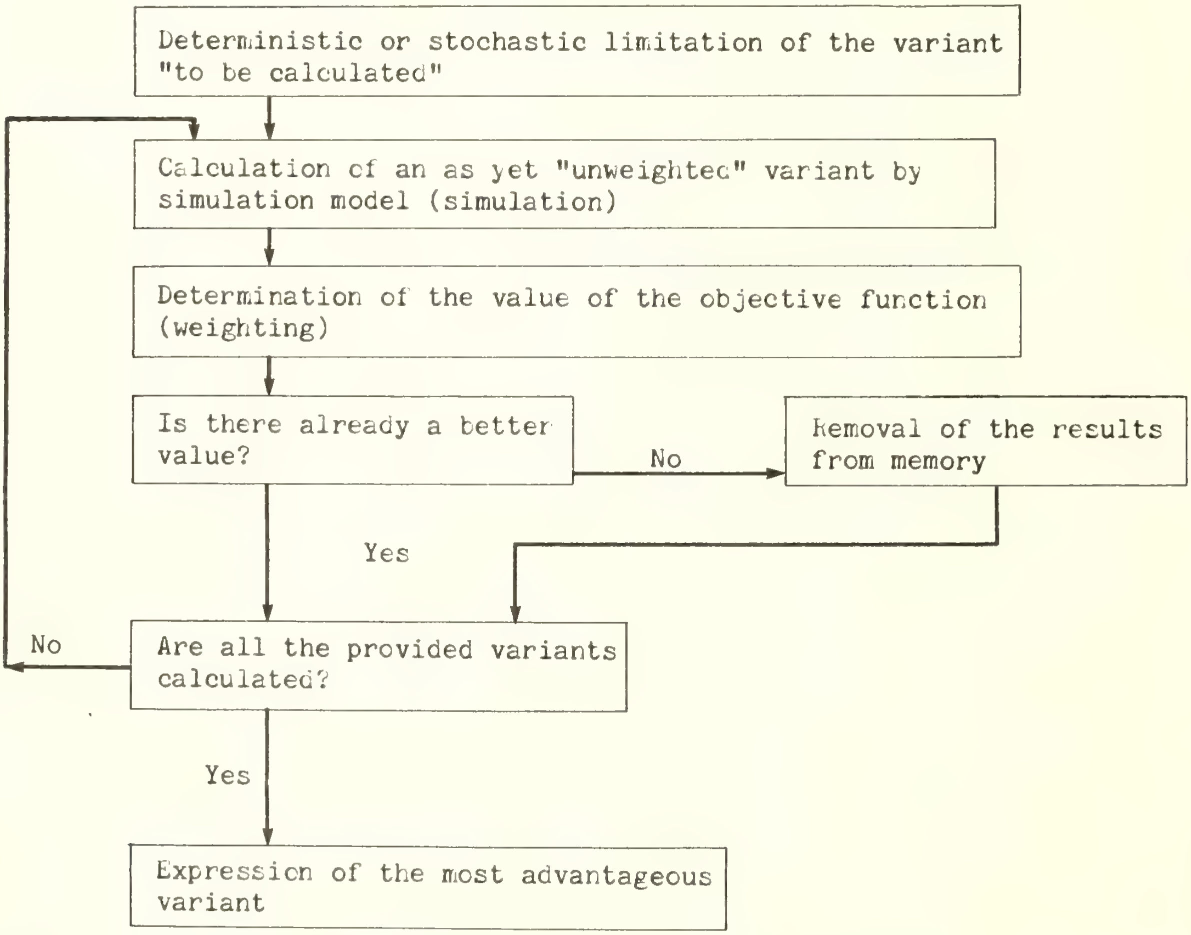
Deterministic or stochastic limitation of the variant "to be calculated"
Calculation of an as yet "unweighted" variant by simulation model (simulation)
Determination of the value of the objective function (weighting)
Is there already a better value?
No
Removal of the results from memory
Yes
No
Are all the provided variants calculated?
Yes
Expression of the most advantageous variant

Figure 1--Principle of mathematical simulation in the form of a flow diagram.

FOUNDATIONS OF THE MANAGEMENT CLASS SIMULATION

The significance of simulation for forestry problems is conditioned primarily by the long duration of the production process. The extensive time differences between managerial measures and their effects on the forest necessitates the inclusion of future developments in present decisions. The value of a measure can be interpreted only in view of its effect on long-term goals.

The management class as a system within a sustained unit is decidedly significant for the complex planning of a forest evaluation. Its stratified structure is only ascertainable through simulation of multiple alternatives in its combined time and space-related development. A management class simulator (Gerold 1976) is a model based on the specific state of a tree species management class, which includes all stands of a tree species cultivated for similar production goals and found within a sustained unit. With this model, the effects of different variants of production and yield regulation on the development of this management class over long periods of time (the prognosis) can be analyzed. Also, the mutual correlation of the component problems of the sustained unit can be demonstrated. The formulation of this type of model has the following foundations and requirements:

(a) The model must be integrated into the total planning system of the forest evaluation. It must have numerous alternatives and include, therefore, many component problems of sustained yield regulation. The time interval over which simulation takes place should be determined by the user.

(b) The stand is the active element in a management class. The complex sustained yield regulation requires that the input information of the simulator refer to this conditional unit. All management class data are derived from the aggregation of stand information during simulation. The accuracy of stand information should be known, to correctly classify the results of the simulation model with respect to certainty within the framework of the decision aids.

(c) Component models, weighted and easily integrated into the planning system of forest evaluation, are to be used for the generation of many alternatives (e.g., intermediate and final yield strategies), i.e., a large scope, in the formulation of a model. The scope of the alternatives is determined by the flexibility and quality of the management class simulator.

(d) An efficient, updating algorithm, which guarantees certain extrapolation, is necessary for the simulation of stand information.

(e) The model must make possible the processing of management classes of any stand, i.e., of any age, quality, and growing stand density structure. If the memory capacity of the electronic data processing unit is not sufficient for calculation of larger conditional units, because stands are numerous, then the stands are aggregated into "computation units of a higher order." In this case, the criteria must be as follows:

Age (e.g., 2-year intervals)
Quality (e.g., have quality grades)
Density stand volume (units of 10)

This facilitates the use of the simulator for sustained units of any given size.

(f) On the basis of goals formulated for the stands, and of management class information, the actual conditions obtained in the individual stages of the prognostic time span, and the planning magnitude are to be weighted according to valuation criteria for the age structure and the stand density. From the weighting, the deviation from the norm is to be estimated. This weighting facilitates the selection of certain planning alternatives by the planner in the context of the overall goals.

(g) The following prerequisites apply for the preparation of the computed information:
  (1) An electronic data processing unit with a large memory capacity and high calculation speed must be available.

  (2) The simulation program is based on the block principle to provide flexible subroutine exchange, thereby making possible simple consideration of new alternatives.

  (3) The presentation of results using a high speed printer must be in the form of clear and easily visible tables. Automatic symbol equipment to represent the development of specific key numbers of the management class are to be used as much as possible.

  (4) The preparation of stand information is rationally possible only through electronics. An additional prerequisite is a functionally efficient, permanently actualized data memory containing information which can be recalled at any time using available sorting identifiers.

Figure 2 presents the general program design of a management class simulator to calculate a planning variant. Any of the available variants (alternatives) can be simulated using this sequential scheme.

DESCRIPTION OF A MANAGEMENT CLASS SIMULATION MODEL

A management class simulator was developed on the basis of the fundamentals presented in Figure 2. It is submitted as the program flow chart and calculation program using the program language ALGOL for the electronic data processing unit BESM-6. The Soviet large-capacity computer is suitable due to its high calculation speed of an average of 10^6 operations/second for the generation of the simulation model. The memory capacity of BESM-6 permits direct processing of management classes with a maximum of 3800 stands. On the average, this corresponds to an information scope of approximately 5000 hectares. For larger conditional units, an aggregation (see figure 2) should be used. The stand data used (age, land, mature crop, quality) are available in handbooks of forest management in the data bank of the forest fund. Extensive information for various planning strategies is derived from these data during simulation for each 10-year period of the prognostic time span. It is printed in the form of the following tables:

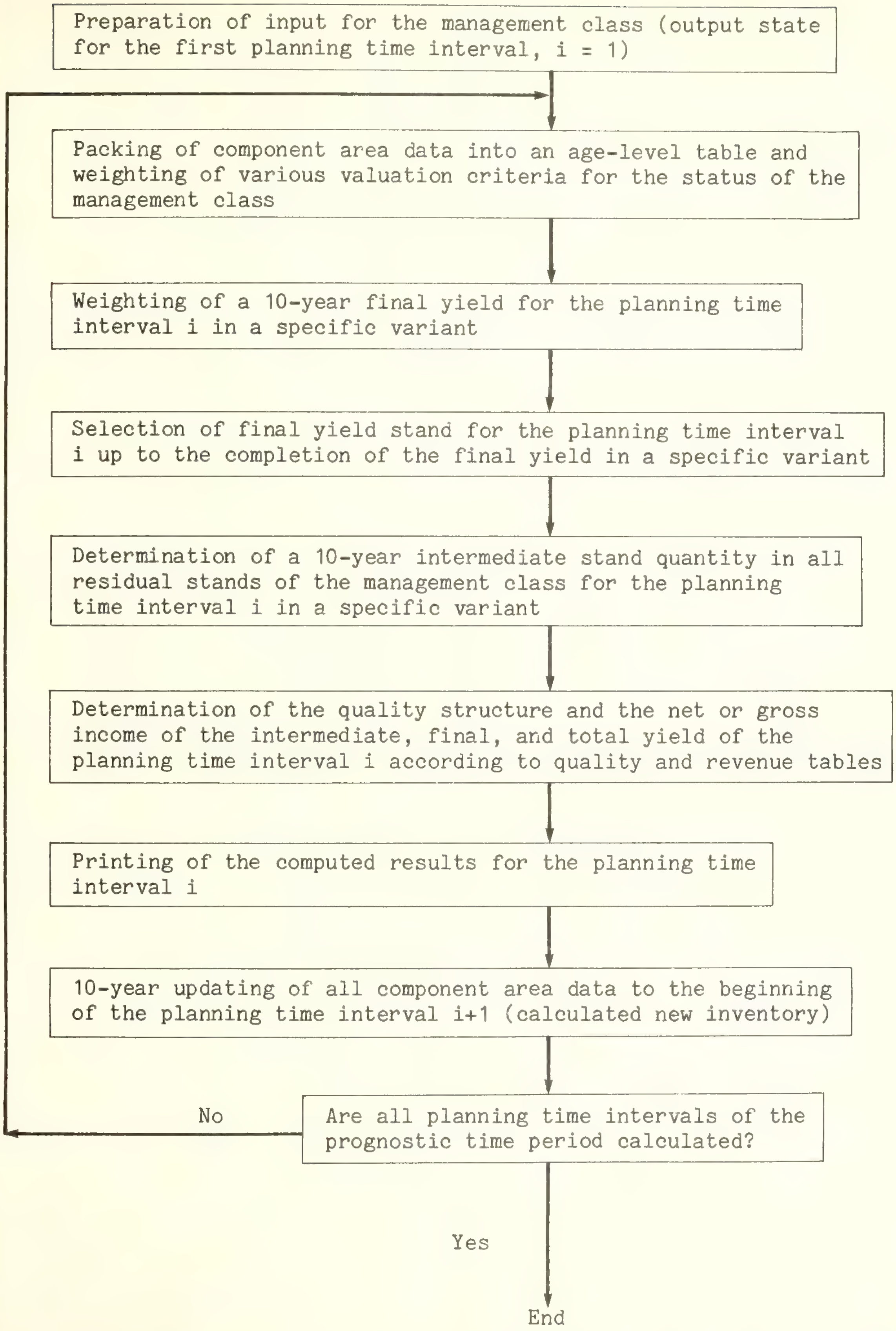
Preparation of input for the management class (output state for the first planning time interval, i = 1)
Packing of component area data into an age-level table and weighting of various valuation criteria for the status of the management class
Weighting of a 10-year final yield for the planning time interval i in a specific variant
Selection of final yield stand for the planning time interval i up to the completion of the final yield in a specific variant
Determination of a 10-year intermediate stand quantity in all residual stands of the management class for the planning time interval i in a specific variant
Determination of the quality structure and the net or gross income of the intermediate, final, and total yield of the planning time interval i according to quality and revenue tables
Printing of the computed results for the planning time interval i
10-year updating of all component area data to the beginning of the planning time interval i+1 (calculated new inventory)
No
Are all planning time intervals of the prognostic time period calculated?
Yes
End

Figure 2--Representation of a general program design in the form of a program flow chart for a specific planning variant.

Age distribution table

Table for final cutting stands

Table for intermediate yields of stands

Summary of harvest and growth

Table of the range of harvest.

The simulation model is constructed in a deterministic manner; i.e., alternatives do not have any random features. Its functional efficiency was tested in a series of real management classes (Gerold 1976; Gerold and Kurth 1977; Kurth and Gerold 1977; Gerold 1978).

LITERATURE CITED

Gerold, D. 1978. Effect of age structure on the growth increment capacity of management classes. Wiss. Ztschr. der Tech. Univ. Dresden, 27:(2).

Gerold, D. 1976. Untersuchungen zu Problemen der Verknupfung einzelner Nachhaltbegingungen mit Simulationsmodellen fur die Baumart Fichte [Investigations on the problem of decisions for individual sustained conditions using simulation models for spruce species]. Dissertation A, Tharandt.

Gerold, D., and H. Kurth. 1977. Proposals for further development of a normal forest model. Wiss. Ztschr. der Tech. Univ. Dresden, 26:(2)497-501.

Kurth, H. and D. Gerold. 1977. Simulation model for sustained yield regulation. Paper presented at the IUFRO Symposium, Subject Group S.04, Session Zvolen. Sept. 12-15, 1977.

A Computerized Tree Growth Projection System for Forest Resource Evaluation in the Lake States

Allen L. Lundgren   Burton L. Essex

Abstract: A computerized tree growth projection system has been developed for the Lake States Region as part of a larger Forest Resources Evaluation Program (FREP). Incorporating data from more than 1500 permanent growth plots throughout the Lake States, this system projects tree growth, mortality, regeneration, and removals in stands with any mixture of tree species and sizes, for the full range of sites encountered in the field. It incorporates the latest published timber management guides for the Lake States. It can identify silvicultural treatment opportunities now and in the future from the plot data or representative tree lists for a single stand, a management unit, an entire forest property, or an entire state or region. It can also be used to update timber inventories and to project future yields and resource conditions in response to alternative silvicultural treatment opportunities for timber resource evaluation and assessment.

INTRODUCTION

A comprehensive inventory of forest resources is essential for land management planning, but by itself is not sufficient. An inventory provides a detailed picture of the resource at one point in time. The forest is not a static entity, but a dynamic biophysical system. A full description of such a system must contain not only an estimate of its present state, but also a description of its potential future change. Without provision for continual updating, an inventory only produces a fading portrait of a resource that is changing with each passing year as regeneration, growth, death, and cutting of trees takes place. To be fully useful to the land manager and planner, a complete resource inventory system should continually update the inventory to provide current data about the condition of the resource. It also should be capable of estimating future changes in the forest resource in response to a range of possible resource management alternatives, including that of no tree cutting.

A tree growth projection system is a necessary part of a dynamic forest resource inventory system. It must be capable of updating and projecting timber inventories in a form suitable for evaluating resource management alternatives for large areas with diverse forest conditions. To do this, it must be able to handle all species and stand conditions in a forest area, require only a minimal amount of input data such as would be available from existing resource inventories, and be computationally efficient.

Developing a tree growth projection system capable of describing the dynamic behavior of complex ecological communities such as the intricately mixed northern hardwood-conifer forests of the Lake States has long challenged inventory specialists and growth modelers. Stand growth models have been developed for several single-species forest types such as *Pinus resinosa* Ait. (Buckman 1962), *Picea mariana* (Perala 1971), and *Populus tremuloides* (Schlaegel 1971). Such models have been useful in developing stand management recommendations for even-aged stands with a single species. However, models have been developed for only a few Lake States species, and existing models fail to describe the behavior of the mixed-species, mixed-sized stands common to the Lake States. Stand models have been developed for some mixed-species forest types for some areas of the Lake States (for example, Dale 1972, Ek 1974, and Moser 1972), but again coverage of the resource base is far from complete. Individual tree models for more general mixed-species stands (Ek and Monserud 1974) are expensive to run and require more data than is available from most forest inventories.

Available growth models have provided valuable insights into tree and stand growth, but by themselves are not adequate for a forest-wide tree growth projection system. Efforts to assemble individual growth models and link them into a more comprehensive system have been frustrated by the lack of common input requirements and data outputs, as well as incomplete coverage of the resource.

TRAS, a computer program for projecting timber volumes, was developed and used by the U.S. Forest Service to update inventories and project future timber volumes for large forest areas (Larson and Goforth 1970). However, this program was not designed as a stand model to account for interactions among size classes of trees in response to alternative silvicultural treatments. It lacks the ability to closely model biological tree response to stand treatments in the mixed forest ecosystems common in the Lake States in the detail needed for evaluating treatment opportunities.

The need is to develop a comprehensive tree growth projection system specifically designed to project tree growth for all species in all stands for large diverse forest areas in enough detail to update forest inventories and evaluate stand treatments.

THE PROJECTION SYSTEM

After several years of work, scientists at the North Central Forest Experiment Station of the Forest Service (U.S. Dep. Agric.) have completed and tested a computerized tree growth system for the forests of the Lake States Region. Developed using data from more than 1500 permanent growth plots in all major forest types in the Region, the projection system reliably projects stand development with or without tree cutting for several decades for all forest conditions found in Michigan, Minnesota, and Wisconsin.

This system inexpensively projects individual tree growth, mortality, and regeneration, with or without tree removals, for products in stands with any mixture of tree species and sizes, and any density, over the full range of sites encountered in the field. The latest published timber management guides for the Lake States species are incorporated into the system. These are used to identify silvicultural treatment and timber harvesting opportunities, now and in the future, from the plot data or representative tree lists used to describe a single stand, management unit, or an entire forest property, state, or region. The projection system has been linked to the U.S. Forest Service's national forest inventory system in the North Central Region. However, it can be adapted readily to other growth projection needs.

Input to the projection system is a list of individual trees that represent a forest stand. At a minimum, the list must have the tree species and diameter breast high of each tree listed, along with each tree's expansion factor to indicate the number of trees per acre each tree represents. Other information should include tree condition (alive, cut, or dead), and stand variables such as site index and age. Tree growth, mortality, and regeneration are projected for any time period (in increments of a year) or sequence of periods selected by the user.

A major advantage of this projection system is that the integrity of the individual tree list is maintained throughout the projection period, so no information about the resource is lost through aggregation. At the end of each projection period, the system produces an updated list of trees in the same format. Thus, programs available to summarize data from the initial tree list or inventory can be used to summarize data from the program output tree lists as though they were a new inventory. It will be necessary to update other data that are subject to change that are not handled by the projection system at present, such as land use or ownership change, changes in site index due to change in forest type, and special tree measurements such as merchantable bole length, log grades, or cull percent.

Silvicultural treatment prescribed for each acre each year or time period is identified by kind of treatment and forest type. A cost algorithm determines the cost of each treatment by time period for the acres indicated. Trees to be cut are designated by the appropriate silvicultural treatment. The system then projects stand development forward for the desired number of years with the trees left after cutting. If desired, the process may be repeated. Timber harvested in each time period can be produced in detail, including cubic foot volume by species and 2-inch diameter class within each type. Mortality volumes can also be summarized in detail. Inventory volumes before and after each cut can also be obtained in the same way. The difference in future stand development with and without treatment can be identified from this information and can be used for economic appraisal of stand treatment opportunities, either on an individual stand or forestwide basis.

The timber projection system has been tested extensively and has provided results well within acceptable limits of accuracy. The tests consisted of projecting first occasion inventory plots, which had not been used to develop model coefficients, and comparing the projected value with actual values that were recorded on sucessive plot measurements.

The system was designed for inexpensive computing so thousands of survey plots could be updated annually to provide current Regionwide inventory data. Computing costs have been about 6 cents to project the tree list from a single plot for 10 years and develop summaries of inventory and harvest volumes.

USE OF THE SYSTEM

This Lake States system has been used to update all the survey plots in Wisconsin, from the most recent inventory (1967-69) to 1978. Removals for timber products were accounted for to provide a current inventory estimate. Similar inventory updates have been done for individual national forests in the Lake States. Plans are to periodically update each state-wide inventory as needed to provide estimates of the current status of the forest resource throughout the Region in as much detail as the original inventories.

The system also has been used to update and project inventories of individual national forests, of all state-owned land within a state survey unit, and of other forest land in response to silvicultural treatment opportunities for timber production. The output showed timber volumes harvested and timber volume inventories by decade for the next fifty years.

The development of individual stands in several National Forest Compartments in Michigan was projected for fifty years, both with and without timber cutting, to show how the system could be adapted to the Forest Service's compartment examination procedures. These illustrate only some of the ways the system can be used.

THE SYSTEM'S POTENTIAL

This timber growth projection system is designed to be the core of a larger Timber Resource Evaluation System, that will evaluate timber management opportunities on a local, state, or regional basis from an economic, social, or ecologic point of view. The evaluation system is still being developed, but the output from the projection system can be used with existing evaluation procedures and programs. The mathematical structure underlying the timber projection system was designed to allow for including other components of the ecosystem besides trees--for example, a link between trees and understory vegetation is now being developed.

The timber projection system developed for the Lake States has tremendous potential. Now, for the first time, we have a computerized system that can project forest resource development in response to timber cutting, or no timber cutting, for all forest conditions in the Region. It answers the longfelt need for a method to project future renewable resource supplies in response to treatment for evaluating management opportunities. It will be useful for timber management planning and program development for state and regional resource assessments. Further, it can be used to update resource inventories to provide a reliable current estimate of present resource conditions.

The concepts used in developing the timber projection system are general and have potential for wide application. We plan to continue development of FREP as rapidly as possible, expanding the system to the rest of the North Central Region and to other resources. We also plan to work with others to test the applicability of the FREP tree growth projection system to other regions of the United States.

Another exciting concept will be to incorporate the tree growth projection system into the remeasurement design of forest inventories. A first step of the new inventory procedure could be to classify plots established at the time of the previous survey into disturbance classes. This might be done using LANDSAT data, conventional photography, or a combination of the two. Undisturbed plots could be grown to the date of the present survey using the tree growth projection system. These plots could then be sampled to determine what corrections, if any, need to be made in the projections to represent current inventory conditions accurately. Disturbed plots could be remeasured on the ground, together with new plots such as might be found in agricultural areas that have reverted to forest. These plots would be processed in the conventional way. The two data sets would then be combined to form the information base for the new survey.

This procedure could substantially reduce the cost of today's remeasurement surveys but still provide a detailed tree list of each plot that may be used in the projection system.

Acknowledgment: The timber growth projection system was developed jointly by a team of researchers at the North Central Station. This team included Dr. Rolfe A. Leary, Jerold T. Hahn, Roland G. Buchman, Gary Brand, Brad Smith, Margaret Holdaway, Jerrilyn LaVarre Thompson, and Linda Christensen, each of whom had responsibilities for major aspects of the study. A collection of papers outlining the system in some detail is being published as USDA Forest Service General Technical Report NC-47, North Central Forest Experiment Station, St. Paul, Minn.

APPENDIX[1]

A general description is given here of the input needed, how the parts are put together, and what output is produced.

Input

The input consists of a parameter deck and a tree list. A tree list consists of tree species, d.b.h., crown ratio, and quality class for a group of individual trees. Also required are the following plot attributes: site index, stand age, and plot size.

Parameter deck

The parameter deck specifies two groups of input values: (A) user selected options and (B) numerical constants needed by each portion of the growth processor.

Numerical constants are used for

Assigning species group codes to individual trees
Crown ratio function coefficients
Silvicultural treatment specifications
Volume equation coefficients
Mortality equation coefficients
Potential growth function coefficients
A species grouping priority matrix (used for combining species when more than three species occur on a plot)

These values are determined from calibrating the model on a specific data base of permanent (remeasured) plots.

Projection-related options that may be selected by the user are

Length of projection cycle (years)
Number of projection cycles
Type of growth projection desired (validation, projection, or update).

The number of years the tree list is projected is determined by the number and length of the cycles. The projection is limited to a maximum of 100 years but it may be in the form of 100 cycles of one year each or one cycle of 100 years. The length of the cycle determines how often summaries are made and the tree list examined for management opportunities.

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[1] This material is abstracted from a forthcoming publication: Hahn, Jerold T., and Gary Brand, A program for implementing a generalized forest growth projection system. USDA Forest Serv. Gen. Tech. Rep. NC-47, North Central Forest Exp. Stn., St. Paul, Minn.

Three different types of growth projections can be selected: validation, projection, and update. A validation run uses a tree list with measurements recorded for several different years. The tree list is projected from the initial measurement to the final measurement. Projected and actual measurements are compared to determine the accuracy of the model. A projection run begins with initial conditions and grows the trees for a specified length of time to estimate future conditions. An update run begins with initial conditions from the past and grows the trees to the present. Known product removals are used to extract the trees that produce those products from the tree list.

Tree list

The tree list can be in one of three different formats: (1) a list format, (2) a unit record format as used by the U.S. Forest Service Renewable Resources Evaluation (forest survey) projects, or (3) a computer-readable format in which the user is responsible for supplying the necessary computer code for input and output routines.

PROGRAM ORGANIZATION

Besides providing input/output capability, the program controls when the different parts of the system are used according to the options selected. The listing below gives all the subroutine and funtion names, their calling routines, and a brief statement of their purpose. The program has seven parts:

1. The main calling program
2. A function, VALUE, where all mathematical equations are located
3. Input subroutines
4. A subroutine for aggregating the input tree list
5. Stand treatment subroutines
6. Stand growth subroutines
7. Output subroutines.

Subsystem TRES (Timber Resource Evaluation System) of program FREP (Forest Resources Evaluation Program)

1. Main program

Program TRES

Main calling routine, sets up and initializes arrays, performs housekeeping functions, organizes calling of subroutines.

2. Mathematical functions

Function Value

Called from RMASTR, RSURTP, GROW, ISUM, OUTPT1, and OUTPT2. Computes values for crown ratio, potential growth, modifier, mortality, and volume.

3. Input

Subroutine READ

Called from TRES

Reads user-selected options and numerical constants and echo-prints all values.

Subroutine RMASTR

Called from TRES

Reads data from binary files in MASTER format into arrays TRS and ITRS.

Initializes array parameters.

Subroutine RSURTP

Called from TRES

Reads data from files in forest survey unity record format into arrays TRS and ITRS.

Initializes array parameters.

Subroutine OPENRD

Called from RSURTP.

Unblocks forest survey unit record file and supplies one record at a time to RSURTP.

Has entry point READIT.

Subroutine RUSER

Called from TRES.

Supplied by user to read their data file into arrays TRS and ITRS.

4. Aggregation of species

Subroutine FIT

Called from TRES, SCREEN, and REMOVE.

Classifies trees in arrays TRS-ITRS into projection groups.

5. Stand treatment

Subroutine SCREEN

Called from TRES.

Screens plots for possible treatment and/or sets up treatment schedule.

Subroutine COVTYPE

Called from SCREEN.

Determines cover type using live trees in tree list.

Subroutine TREAT

Called from SCREEN.

Performs silvicultural treatments prescribed in SCREEN.

6. Stand growth

Subroutine GROW

Called from TRES.

Grows trees, selects trees for mortality, updates TRS and ITRS array.

Subroutine REMOVE

Called from GROW

Removes trees to meet specified annual removals for updates or trees recorded as having been removed by remeasurements.

Subroutine ISUM

Called from GROW, OUTPT1, TRES

Summarizes trees into classification groups and computes group totals.

7. Output

Subroutine OUTPT1

Called from TRES.

Outputs summaries for specified points in time.

Subroutine TFILE

Called from TRES.

Outputs updated forest survey unit record file.

Subroutine OPENWR

Called from TFILE.

Writes blocked unit record tape.

Has entry points WRITIT and CLOSWR.

Subroutine OUTPT2

Called from TRES.

Outputs file for validation tests.

Subroutine OUTUR

Called from TRES.

Supplied by user to output updated tree list to their specifications.

When all input (parameters and tree list) has been read, the tree list is partitioned into species groups and size classes by subroutine FIT, called from the main program, TRES.

Selecting the option to manage the stand as it is being projected, causes subroutines SCREEN, COVTYPE, and TREAT to be called. COVTYPE, which is also called at the end of a projection by OUTPT2, determines the cover type and TREAT performs the silvicultural treatments selected in SCREEN. Trees selected for removal are designated as cut and the live trees are again divided into species and diameter groups by a recall of subroutine FIT. This allows the changes in species composition caused by cutting to change the species groups thereby changing the numerical constants used to project the plot.

The tree list is projected one year at a time for the number of years in a cycle by subroutine GROW, REMOVE and ISUM. The crown ratio function, potential growth function, and modifier function are used to determine individual tree growth. Dead trees are determined using the mortality function and the pseudo-random number generator.

OUTPUT

Four different output types are possible:

(1) "Yield table" type output containing such variables as basal area and number of dead trees, number of surviving trees, basal area and sum of diameters on a per plot and per acre basis, and cut tree volumes on a per acre basis. This output is given by subroutine OUTPT1 and is available at the end of each cycle as well as at the beginning and end of the projection period.

(2) A new Renewable Resources Evaluation (forest survey) unit record file (subroutine TFILE and OPENRD).

(3) A file for validating the projection system. This is produced by subroutine OUTPT2 and has meaning only if two or more measurements have been made on the plot. The file produced by OUTPT2 is ordinarily stored on disk and analyzed by a separate user-written program.

(4) A user-designated output file (subroutine OUTUR).

LITERATURE CITED

Buckman, Robert E. 1962. Growth and yield of red pine in Minnesota. U.S. Dep. Agric., Tech. Bull. 1272, 50 p., illus. Wash., D.C.

Dale, Martin E. 1972. Growth and yield predictions for upland oak stands 10 years after initial thinning. USDA Forest Serv. Res. Paper NE-241, 21 p., illus. Northeastern Forest Exp. Stn., Upper Darby, Pa.

Ek, Alan R. 1974. Nonlinear models for stand table projection in northern hardwood stands. Can. J. For. Res. 4(1):23-27.

Ek, Alan R., and Robert A. Monserud. 1974. FOREST: a computer model for simulating the growth and reproduction of mixed species forest stands. Res. Rep. Sch. Nat. Resour., Univ. of Wis., Madison, Wis. 85 p., illus.

Larson, Robert W., and Marcus H. Goforth. 1970 TRAS--a computer program for the projection of timber volume. U.S. Dep. Agric., Agric. Handb. 377, 24 p., illus.

Moser, John W., Jr. 1972. Dynamics of an uneven-aged forest stand. Forest Sci. 18(3):184-191.

Perala, Donald A. 1971. Growth and yield of black spruce on organic soils in Minnesota. USDA Forest Serv. Res. Paper NC-56, 16 p., illus. North Central Forest Exp. Stn., St. Paul, Minn.

Schlaegel, Bryce E. 1971. Growth and yield of quaking aspen in northcentral Minnesota. USDA Forest Serv. Res. Paper NC-58, 11 p., illus. North Central Forest Exp. Stn., St. Paul, Minn.

Techniques of Australian Forest Planning

Australian Forestry Council

Research Working Group No. 2[1]

Abstract: Computer modeling has been extensively adopted for Australian forest planning over the last ten years. It has been confined almost entirely to the plantations of fast-growing species for which adequate inventory, growth, and experimental data are available. Stand simulation models have replaced conventional yield tables and enabled a wide range of alternative strategies to be evaluated for each individual stand. Simulation models for entire plantations have been found invaluable for the preparation of 1- to 5-year cutting plans and for regulating the yield over 20- to 60-year periods. Many models have been constructed and found to be simple and highly cost-effective. Optimization models, using linear programming, have been constructed for yield regulation and found to give powerful insights into the interactions between the various alternatives available for all stands. However, these models are expensive and require considerable data and expertise. They are difficult to maintain, especially when staff change.

INTRODUCTION

This paper reviews Australian experience with the planning techniques used for plantations, and some even-aged natural forests, in the light of their potential usefulness to developing countries. Australia has a century of experience with industrial plantations of fast-growing exotic species, such as Pinus radiata, which have been planted extensively in developing countries in recent years. During the last 10 years, planning methods have been completely changed by the development of computer modeling techniques and it is to experience gained in this change that the paper is addressed.

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[1] Research Working Group No. 2--Mensuration and Management is one of several groups set up by the Australian Forestry Council. It consists on one or two planners from each of seven government forest services, as well as representatives from industry and universities. Members of the group are concerned both with developing new models and with the routine preparation of management plans based on their results.

The extent to which modeling has been adopted, and the type of models developed, in each region have been determined largely by the data required and available. Data collection in the mixed-species, mixed-age, natural hardwood forests is very difficult and has often not been warranted by the slow growth and low value of the stands; very few models have been built for these forests. By contrast, extensive inventory, growth, and experimental data have been collected for long periods in the single-species, even-aged, fast-growing, and valuable plantations. It has been found often that the available data did not cover as wide a range as was needed to enable models to examine new options for the future. In particular, existing inventory data has rarely been suitable for the construction of growth models. Wider ranges are being included in the designs of many new experiments.

Thorough testing of the models is of great importance and is generally done on a continual and long-term basis by comparing estimated yields with actual deliveries to mills. Several effects, such as errors of growth estimation or modeling thinnings, quantity of residues, degree of utilization and conversion factors, are confounded in such comparisons. However, adequate performance in the tests is essential for management acceptance of the forecasts made by the models.

SIMULATION OF GROWTH AND YIELD

The simulation of growth and yield with computer models has been a considerable advance on the use of standard yield tables because the effects of many more silvicultural and management options can be examined quickly, and because the individual conditions of each stand can be allowed for.

Each model described comprises several biometric functions, forecasting the development of various stand parameters, which are combined into a compatible system enabling the stand as a whole to be characterized. The key functions are those to forecast height and basal area or volume growth and to estimate the effects of tree breeding and alternative silvicultural options such as cultivation, fertilization, or thinning. Almost all these functions were constructed with data from repeated measurements of permanent growth plots and designed experiments and only a few from stem analysis or inventory data.

Some other functions, such as those describing stem form or volume, basal area, and height relationships, are also needed. Useful functions were often prepared initially by hand-drawn graphical analysis, and early modeling was based on computerized versions. Linear regression analysis has now almost entirely replaced graphical analysis. More advanced forms of analysis are being introduced such as nonlinear estimations and generalized least squares. As some extrapolation has almost always been necessary, the forms of the growth functions have had to be chosen very carefully.

There has been a gradual shift towards more intensive silviculture in Australia, as elsewhere in the world. The stands now being planted are expected to grow differently from those which provided the data for the growth functions currently used. The methodology needed to allow for this difference, the nature of interactions between effects (e.g., tree breeding and thinning), and the long-term upper limits to growth of stands grown under new conditions are matters requiring considerably more research.

Stand Simulation Model 1

Organisation : A.P.M. Forests Pty. Ltd.,
P.O. Box 37, Morwell, Victoria 3840.

Information : J.B. Dargavel

Forest : 40,000 ha of **P.radiata** supplying a pulpmill and a sawmill. There is a wide range of sites and there is very little land available for purchase economically.

Objective : Generate alternative strategies for each stand for subsequent selection by optimisation model.

Time Span : 25 years

Input : Inventory plot data from existing computer system.

Method : Functions constructed by linear regression from permanent growth plot data forecast height and basal area increments. Responses to fertiliser, weed control and tree breeding estimated from experiments. Volume yield by thinning and clear felling calculated by size and wood basic density classes.

Output : Stand development, yield, cash flow for each of an average of 50 alternative strategies for each of 200 stands. Each strategy represents a different combination of

1. establishment method (2 alternatives)
2. thinning method (3 grades)
3. later fertilisation (Yes/No)
4. clear felling age (10 possible ages)

Application : Provide input to plantation optimisation model.

Evaluation in Organisation : Has enabled wide range of silvicultural options to be examined. Major difficulties are estimation of how stands will grow under combinations of alternatives that have not yet been tried. Research needed on interactions and upper limits to growth.

Assessment for Developing Countries : Useful for generating yield tables. Tabular presentation of standard or example strategies necessary if immediate computer access not available. Accuracy depends on relevance of growth functions incorporated.

Reference : Turner, B.J., Bednarz R.W. and Dargavel J.B. (1977). A model to generate stand strategies for intensively - managed radiata pine plantations. Australian Forestry 40 (4) : 255-67.

Stand Simulation Model 2

Organisation : Queensland Forestry Department,
388-400 Ann Street, Brisbane, Queensland 4000.

Information : B. Stark

Forest : 38,000 ha of native conifers (predominantly **Auracaria cunninghamii**) and 60,000 ha of Pinus species, predominantly **P.elliottii** and **P.caribaea** but also **P.radiata, P.taeda** and **P.patula.**

Objective : To calculate both short and long term yields, cash flows, and standing volumes and values at any nominated time, for various management alternatives.

Time Span : Short term up to 20 years and long term up to 60 years.

Input : Inventory plot data and 1% dbh strip samples from existing computer system.

Method : Functions constructed from inventory and experimental data forecast height and basal area increments and are used to calculate new diameter distributions. Currently the model requires the alternative strategies for any given stand from a measured sample, but in the future the model will generate the strategy, given certain broad guide lines. A wide range of alternative thinning strategies can be examined.

Output : The model projects and thins the stand table in 1 cm dbh classes for each cutting unit producing estimates of basal area, predominant height, volumes and values.

A very wide range of groupings or listings is available including time period options, stand conditions (basal area, predominant height, age etc.), size assortment by quality classes for the stand and thinnings, volumes and values for the stand or thinnings using current pricing, and tables of predominant height, volume, and basal area information for direct comparison with the actual plots, giving a continuing check on the model predictions.

Evaluation in Organisation : A plantation simulation is provided by aggregating the simulations of each stand. The resulting short term calculation (up to 5 years) has been very successful in organising logging and new sales.

Assessment for Developing Countries : Possibly the basal area increment prediction method could be very useful to countries with young plantations and limited data.

Stand Simulation Model 3

Organisation	Woods & Forests Department, P.O. Box 162, Mount Gambier, South Australia 5290.
Information	N.B. Lewis, A. Keeves and J.W. Leech.
Forest	70,000 ha of **P.radiata** plantations, managed on an approximately 50-year rotation with up to six commercial thinnings, and with a comparatively even distribution of age classes.
Objective	To predict the yield of plantation stands of radiata pine from age 9½ site quality assessment to the end of rotation.
Time Span	10 - 50 years.
Input	Permanent sample plots data - plots measured for volume every 2-3 years. Some plot trends exceed 40 years.
Method	Graphical methods using the directing curve technique.
Application	Incorporation in long term planning models for even-aged stands.
Evaluation in Organisation	The technique has been used successfully for over 30 years to regulate the total cut from a profitable state afforestation enterprise, keeping the cut as near sustainable maximum as possible. The model is very nearly as precise a prediction model as the best nonlinear model developed.
Assessment for Developing Countries	Advantages – 1. it is simply revised as more data becomes available. 2. being subjective, local knowledge of data relevance and accuracy can be incorporated. 3. does not need computer. 4. does not need statistical expertise. Disadvantages – 1. precision is unknown. 2. it may be biased.
References	Lewis, N.B., Keeves, A. and Leech, J.W. (1976) "Yield regulation in South Australian Pinus radiata plantations". Woods & Forests Bulletin 23. Adelaide.

Stand Simulation Model 4

Organisation	Woods & Forests Department, P.O. Box 162, Mount Gambier, South Australia 5290.
Information	J.W. Leech.
Forest, Objective, Time, Input	As for Model 3.
Method	An alternative to the method used in model 3. Nonlinear regression analysis using Generalised Least Squares and optionally, Bayesian informative priors.
Output	It will be incorporated in a revision of the South Australian plantation simulation model for long term planning.
Application	Incorporation in long term planning models for even-aged stands.
Evaluation in Organisation	The algorithms used offer considerable advantages over the commonly used linear regression analysis using Ordinary Least Squares :– 1. alternative biologically sound, hypothetical models can more readily be formulated as nonlinear models than as linear models. 2. Generalised Least Squares provides a statistically sound way of utilising long term trend data. 3. Bayesian statistical methods enable thinned and unthinned plot data to be incorporated in the one analysis. These complex techniques are necessary if a mathematical model for radiata pine is to be a superior predictor to yield tables developed by the directing curve trend technique. Further, these extensions provide a more precise prediction model that is statistically sound.
Assessment for Developing Countries	The technique used requires good long term data which could be obtained only from – 1. remeasured plots, or, 2. stem analysis.

Stand Simulation Model 4 contd.

Further the technique requires access to computing facilities and also requires a sound statistical knowledge.

Given these factors the technique offers considerable promise for yield prediction in even-aged stands.

References : Ferguson, I.S. and Leech, J.W. (1978)
"Generalised Least Squares estimation of stand yield functions". Forest Science (in press).

Stand Simulation Model 5

Organisation : Tasmanian Forestry Commission,
199 Macquarrie Street, Hobart, Tasmania 7000.

Information : P.R. Lawrence.

Forest : 29,000 ha of **P.radiata** plantations managed for sawlog and pulpwood production on rather conservative thinning regimes, delayed to varying degree because of poor current market demand.

Objective : To predict thinning and clear-felling yields from stands of various ages, site indices, stocking class and thinned states. Inclusion in forest simulation model, assuming current treatment regimes.

Time Span : Up to 40 years in periods of up to 3 years.

Input : Either data from sample plots or, when used in the forest model, estimated values of mean dominant height, basal area and mean dbh obtained from age, site index and thinned state of each patch of forest recorded in the area information system.

Method : The three basic parameters predicted are mean dominant height, basal area increment and increment in mean dbh. The height/age relationship was obtained by non linear methods, the other two by linear least squares, all from permanent plots. Thinning yields and the new starting point after thinning are predicted from past records of standard treatment. Volumes are calculated from stand volume equations.

Output : Values required for the forest simulation model including mean dbh, entire stem volume and volume to four top diameter limits for either thinnings or clear-fellings.

Application : Simulation of a forest.

Evaluation in Organisation : The major limitation is that the results can only apply to stands treated in the same manner as in the past. Since new treatment regimes are being adopted, the use of these models in very limited. The major source of inaccuracy of prediction was found to be in estimating the starting points.

Assessment for Developing Countries : Few developing countries are likely to adopt the very conservative thinning regimes modelled.

Stand Simulation Model 6

"STANDSIM"

Organisation : Forests Commission, Victoria,
601 Bourke Street, Melbourne, Victoria 3001.

Information : R.B. Smith.

Forest : Even aged monospecific natural stands **Eucalyptus regnans, E.delegatensis, E.sieberi** and approximately 75,000 ha of **P.radiata** plantations.

Objective : The future growth of a stand of any age is modelled for any period, for various sites and thinning regimes.

Time Span : Commonly 25 - 40 years, with annual or 5 yearly growth cycles.

Input : Individual tree data by 10 cm size classes also rotation length, site index, thinning regimes.

Method : STANDSIM is a deterministic model which projects the development of a hectare of forest for various sites and thinning regimes, operating on individual tree data stored mainly as an array of tree diameters. In each growth cycle the trees are grown and if necessary thinned by natural mortality or cutting. Growth takes place by updating the diameters according to gross basal area increment and other functions.

Output : At the end of each growth cycle, stand data including basal area, stocking and dominant height of live trees, gross increment, net increment, mortality, and thinning information.

Application : Output from this model is used in systems for scheduling the cut from large areas of forest. It can also be used to study a range of cutting options, for example, the number and timing of thinnings, and timing of final harvest. A stochastic version of this model has been developed for studies of risk and uncertainity.

Stand Simulation Model 6 contd.

Evaluation in Organisation	The model has been highly successful because users were involved in construction and testing.
Assessment for Developing Countries	A simplified form of the basic growth model would be potentially useful in even-aged forest areas for which large scale industrial developments are proposed. Advantage – 1. the ability to study a whole range of thinning and clear felling options. Disadvantages – 1. the model refers to monospecific stands only, 2. model assumes fairly regular spacing, 3. no allowance for defective stands.
Reference	Opie, J.E. 1972. STANDSIM - a general model for simulating growth of even-aged stands. Proc. 3rd Conf. Advisory Group of For. Statisticians, Section 25, IUFRO, Jouy-en-Josas, France, Sept. 1970.

SIMULATION FOR CUTTING PLANS AND YIELD REGULATION

Computer models which simulate the future yield of entire plantations, that is, all stands considered together, have become indispensable aids for preparing 1- to 5-year cutting plans and for regulating the yield over 20- to 60-year periods.

The models described in this section simulate the development of the plantations and the production of wood according to initial starting values of such things as the area and conditions of existing stands, land availability, planting rate, and the quantities of wood demanded for industrial developments. Some models include forecasts of cash flows and economic results.

For each year of the simulation, the plantation models forecast the growth of each stand using yield tables or the stand simulation models described earlier. Stands are then scheduled for cutting according to built-in decision rules and the overall yield for the year calculated.

By altering the starting values and repeating the simulations, a range of alternatives can be generated from which the planner can select the most suitable. The models are used to schedule stands for clear felling and to evaluate the timing and type of thinning operations, particularly in relation to the demand for small-diameter roundwood. In long-term planning, the models are used to evaluate alternative planting rates and investigate how proposed new industries might be supplied.

The models vary considerably in their complexity depending on the extent to which the variations in site are identified and on the nature of the decision rules used for selection. The simplest models consider only the average site and extend the areas of each age class by a standard yield table. By contrast several of the models consider each separate stand and simulate their development with stand growth and yield models imbedded within the overall plantation model.

Plantation Simulation Model 1

CUTTING PLAN

Organisation : A.P.M. Forests Pty. Ltd.,
P.O. Box 37, Morwell, Victoria 3840.

Information : J.B. Dargavel.

Forest : 40,000 ha **P.radiata** plantations.

Objective : Schedule stands for cutting to supply a pulpmill and sawmill.

Time Span : 6 months - 3 years.

Input : The age, basal area, height and stocking of each cutting unit, its area and suitability for summer or winter cutting.

Method : Includes a stand growth model. Selects stands for cutting by priority rules based on operation due, need for thinning, quality of sawlogs and volume to be met.

Output : Schedule of stands to be cut and volume of each product.

Application : Preparation of operational cutting plans.

Evaluation in Organisation : Comparatively cheap to develop. Easy to use and amend.

Assessment for Developing Countries : Cost effective. Scheduling could be done manually.

Reference : Dargavel J.B., and Marshall P.J. 1976. Annual cutting plans for developing plantations. Proc. IUFRO Working Group S 4.02.4 XVI World Congress. Oslo.

Plantation Simulation Model 2

CUTTING PLAN

Organisation : Woods & Forests Department,
P.O. Box 162, Mount Gambier, South Australia 5290.

Information : A. Keeves and J.W. Leech.

Forest : Some 70,000 ha of **P.radiata** plantations, managed on an approximately 50 year rotation with up to six commercial thinnings, and with a comparatively even distribution of age classes.

Objective : To predict the yield of a group of plantation stands of radiata pine in the next commercial thinning.

Time Span : 1 - 6 years.

Input : Inventory data, yield prediction models, proposed thinning treatment and tree size assortment tables.

Method : Linear regression analysis was used to predict tree volume and increment from tree diameter, stand height, site quality and stand density for both thinnings and clear felling. Inventory data are from temporary 0.1 ha plots.

Output : A tabular five year cutting plan listing operations to be carried out and expected yields in a range of size assortments.

Application : In preparing the next 5 year cutting plan which will direct where commercial thinning and clear felling will take place to meet commitments to utilisation plants in a variety of required size and quality assortments.

Evaluation in Organisation : A limited test using independant data indicated the approach was satisfactory for practical use.

Assessment for Developing Countries : This type of model is of use when short term (1-6 year) increment is considerable and will affect planning. This is of particular importance when a fast growing plantation resource is being utilised close to its capacity.

Reference : Lewis, N.B., Keeves, A. and Leech, J.W. (1976) - "Yield regulation in South Australia **Pinus radiata** plantations". Woods & Forests Bulletin 23, Adelaide.

Plantation Simulation Model 3

CUTTING PLAN

Organisation : Forests Department of Western Australia,
Barrack Street, Perth, Western Australia 6000.

Information : H. Campbell.

Forest : 45,000 ha **P.radiata** and **P.pinaster** plantations.

Plantation Simulation Model 3 contd.

Objective : Development of 1 and 5 year logging plans. Planning the timing and extent of forest industry expansions.

Time Span : Open ended, but generally 1 or 5 years.

Input : Continuous inventory plot measurement data.

Method : Simulation of growth by a stochastic model. Thinning operations and silvicultural and marketing priorities are set interactively.

Output : For each year of the planning period a list of areas to be treated and volumes by assortments is produced. Also a resource summary is prepared.

Application : Scheduling thinning operations in pine plantations could also be used to develop strategies for input to an optimising program.

Evaluation in Organisation : After a slow start the model is gaining in use and acceptance in direct proportion to the degree of pressure put on the plantation resource.

Assessment for Developing Countries : The growth routines are specific to radiata and pinaster pine. The modifications required to adapt them to other coniferous species would probably be minimal. Extensive modifications would probably be necessary to adapt them to hardwood species.

Plantation Simulation Model 4

YIELD REGULATION (Four Models)

Organisation : A.P.M. Forests Pty. Ltd.,
P.O. Box 37, Morwell, Victoria 3840.

Information : J.B. Dargavel.

Forest : Plantations of **P.radiata, P.elliottii, E.regnans** and **E.grandis** in New South Wales, Queensland and Victoria developed to supply pulpmills.

Objective : Development planning. Determine if mills of given size can be supported from nominated land areas and planting rates.

Time Span : 20 - 30 years.

Input : 3 models assume one average site; 1 model assumes 4 different sites, models require areas of each age, standard yield table for each site, and standard costs.

Method : Yield table projection. Areas scheduled for clear felling to meet mill demands by nominated priority rules, mostly oldest first.

Output : Schedule of areas planted, thinned, felled. Times at which demands can not be met or surplus available. Condition of plantations at end of planning period.

Application : Development planning, particularly at initial stages of plantation development prior to industries being established.

Evaluation in Organisation : Simple models, easy and cheap to construct and run only require small computers. Very successful when operated in inter-active mode. Used when only limited data available i.e. before extensive inventory data base has been built up. Difficulty is that they ignore real site differences and full range of opportunities that become apparent when inventory and experimental evidence has been assessed; complex optimisation models then developed to evaluate.

Assessment for Developing Countries : Very high as models can be limited to the data available. Cheap and simple to construct and use. Highly cost effective.

Reference : J.B. Dargavel. 1969. Yield forecasting for industrial plantations. Australian Forestry 33 (3) : 153-62 gives details of an early, rather more elaborate model than is currently used.

Plantation Simulation Model 5

YIELD REGULATION

Organisation : Woods & Forests Department,
P.O. Box 162, Mount Gambier, South Australia, 5290.

Information : A. Keeves and J.W. Leech.

Forest : 70,000 ha of **P.radiata** plantations, managed on an approximately 50 year rotation with up to six commercial thinnings, and with a comparatively even distribution of age classes.

Objective : To predict the long term yield of the resource.

Time Span : 60 years.

Plantation Simulation Model 5 contd.

Input	:	Inventory data, yield prediction models, potential thinning regimes, information from the short-term planning model and stand size assortment table.
Method	:	Currently uses yield tables to predict the growth of a logging unit allowing for variations of site potential, but will incorporate mathematical models recently developed. Logging units are thinned according to a variety of commercial thinning regimes and potential yields are aggregated by assortments into years. Yields between years were balanced by varying the clear felling age for some logging units over the first 25 years of the planning horizon.
Output	:	Tables listing thinning and clear felling operations, areas and volumes by assortments included in each year's potential cut, and summaries by five year periods and by forests.
Application	:	Strategic planning of the long term permissible cut.
Evaluation in Organisation	:	The technique has been used successfully to determine long term cutting strategy from a limited forest resource that is now fully committed to industry. A limited range of management strategies can be evaluated, depending on the range of data used to develop the model. The model is deterministic not stochastic. These limitations have not proved significant and the accuracy of the predictions is satisfactory for long term strategic planning in an environment subject to short term change.
Assessment for Developing Countries	:	This type of model is applicable in many developing countries as it can use simple growth - yield - inventory data to estimate wood availability under a variety of management strategies.
Reference	:	Lewis, N.B., Keeves, A. and Leech, J.W. (1976) "Yield regulation in South Australia **Pinus radiata** plantation." Woods & Forests Bulletin 23, 174 pp.

Plantation Simulation Model 6

YIELD REGULATION

Organisation	:	Tasmanian Forestry Commission, 199 Macquarie Street, Hobart, Tasmania 7001.
Information	:	M.L. Higgs.
Forest	:	29,000 ha of plantation, predominantly **P.radiata**, supplying privately owned sawmills, pulpmills and other utilization plants.
Objective	:	To predict thinnings and clear-felling yields by various classes given specified felling age prescriptions and volume constraints.
Time Span	:	Varies depending on need, generally 15 - 30 years.
Input	:	Uniform batches of forest are classified by stand parameters including age, site index class and thinned state.
Method	:	Initially each patch is assigned thinning and clear-felling priority values based on its stand parameters. Stands are then ranked in decreasing priority order for clear-felling or thinning. Yields for stands eligible for felling are accumulated subject to volume constraints. Stand volume, growth, and felling yields are estimated by means of functions comprising the stand simulation model.
Output	:	Annual schedule or areas available for felling. Deficits or surpluses if volume constraints applied. Summary of growing stock at five year intervals.
Application	:	Resource level planning of sawlog and pulpwood sales.
Evaluation in Organisation	:	The model is good where economic considerations with respect to management have not been emphasized.
Assessment for Developing Countries	:	Represents a simple, inexpensive system with potential where optimisation involving cost criteria is not required. Disadvantages are in lack of diverse range of cutting strategies and in not having log assortment output.

Plantation Simulation Model 7

YIELD REGULATION "FORSIM"

Organisation	Forests Commission, Victoria, 601 Bourke Street, Melbourne, Victoria 3001.
Information	R.B. Smith.
Forest	75,000 ha of **P.radiata** plantations.
Objective	To predict woodflows and cash flows from a forest consisting of a set of diverse even-aged stands.
Time Span	Up to 50 years.
Input	Inventory plot records for each section of the forest (sections uniform in age, species, site index).
Method	Growth simulation of plot basal area and height, and simulation of harvesting operations (thinning and clear fellings) depending on the cutting regime.
Output	For each strategy output includes volumes (by size classes), areas and section numbers for each year, areas by age classes, growing stock volumes for nominated years, revenues and discounted revenues for each operation for each year.
Application	Planning and scheduling the cut, testing and comparison of cutting strategies.
Evaluation in Organisation	Highly successful although initial problems with change of staff, change of computing environment, change of measurement units. Ideal application for **P.radiata** plantations where a large number of possible cutting strategies is involved.
Assessment for Developing Countries	The complex FORSIM package would have little potential for forests coming under management for the first time. The simplified version ASSIM may have potential as a short term growth simulator.
Reference	Gibson, B.F., Orr R.G. and Paine D.W.M. 1971. FORSIM – a computer program for planning management of even-aged forests. Forests Commission Bulletin. Melbourne.

OPTIMIZATION FOR FOREST YIELD REGULATION

The three optimization models described in this section were designed for yield regulation. The optimization models represent a significant advance on the simulation models described earlier because they enable the full combination of the silvicultural alternatives, for each stand times the number of stands, to be explored. For example, if there are 50 alternative strategies for each of 200 stands, an optimization model finds the best set out of the 50 x 200 = 10,000 possible alternatives. The best set consists of the strategy selected for each stand, with a few stands being divided into 2 or 3 parts each with a different strategy. Thus a little over 200 alternatives out of 10,000 are selected in a single run of the model. By contrast the simulation models only allow those combinations to be evaluated that are defined in the built-in decision rules.

Two of the models are concerned with large fast-growing exotic plantations of *P. radiata* and one is concerned with extensive fast-growing even-aged natural stands of *E.regnans* and *E.delegatensis*. All the models evaluate various silvicultural alternatives for each stand while meeting overall constraints, such as markets or budget, for the plantation as a whole.

Each model uses a linear program for optimization formulated along the lines originally developed by Clutter (Ware and Clutter 1971) in the Type 1 model of Johnson and Scheuman's (1977) classification. Standard computer packages are used to solve the linear programs and obtain extensive marginal analysis.

The models require extensive data prepared, by a "matrix generator" program, in a form suitable for input to the standard packages. The source data consists of the yields, cash flows, etc., for each alternative strategy considered for each stand. This extensive data is generated by stand simulation models.

The optimization models have been found to be many times more expensive to develop and operate than simulation models. They require very extensive data and considerable expertise. Because of this, they have been found difficult to maintain when specialist staff move. They do, however, provide very powerful insights into interactions between the alternative strategies available for different stands. Their use can best be justified when forest structure and conditions are complex and the supply/demand relationship is critical.

The optimization models were only constructed after substantial experience had been gained both with stand and plantation simulation models.

Optimisation Model 1

Organisation : A.P.M. Forests Pty. Ltd.,
P.O. Box 37, Morwell, Victoria 3840.

Information : J.B. Dargavel.

Forest : 40,000 ha of **P.radiata** in Victoria supplying a pulpmill and a sawmill. There is a wide range of sites, and very little land is available for purchase economically. Some outside wood and chips are purchased.

Objective : Plan plantation development, and ration capital between buying land, planting and fertilisation. Also, find how much outside wood to buy, schedule thinning and clear felling and find best silvicultural regime for each stand.

Time Span : 25 years.

Input : An average of 50 alternatives for each of 200 stands showing yields, cash flows and contribution to objectives, produced from stand model. Volumes and costs of outside wood purchase options. Many other data on conversion factors, costs etc.

Algorithm : Linear programming.

Output : Extensive reporting of:

1. silvicultural regime (planting method, fertilisation, thinning method, clear felling age) for each stand,
2. Wood purchase schedule,
3. Planting, thinning and clear felling schedules,
4. Rationing of capital between all plantation activities,
5. Forecasts of size and density distribution to mills,
6. Marginal costs of all constrained opportunities.

Evaluation in Organisation : Development brought all sections of organisation together. Proved to be a very powerful tool in giving insights into operation of plantation system. Very demanding in data requirements and staff time. Expensive to construct and operate. Requires ready access to large computer. Difficult to modify quickly to changing conditions.

Assessment for Developing Countries : Considerable data and staff time required for both construction and continued modification and maintenance of model in usable and valid condition.

Reference : J.B. Dargavel. 1978. A model for planning the development of industrial plantations. Australian Forestry. 41. (in press).

Optimisation Model 2

"RADHOP"

Organisation : Forestry Commission of N.S.W.,
93 Clarence Street, Sydney, N.S.W. 2000.

Information : R. Wilson and M. McMullen.

Optimisation Model 2 contd.

Forest : 100,000 ha of **P.radiata** plantations with irregular age-class distribution supplying 2 particleboard plants and numerous sawmills.
One or two pulpmills are planned for the early 1980's.

Objective : Rationalise yield flows through time to meet market requirements.

Time Span : Either short term (commonly five years) or long term (commonly 35 years).

Input : Inventory plot data plus financial information.

Algorithm : Stand simulation by deterministic functions constructed from research and inventory data. Optimisation by linear programming, which selects regimes to apply to management units to maximise returns while meeting volume constraints.

Output : Details of regime to be applied to individual areas, size and time distribution of volume.

Application : Short term harvest planning, and long-term prediction of quantity of industry that can be supported at various times.

Evaluation in Organisation : Successfully accepted as major management aid because of demonstrated reliability. Functions continually adapted as conditions change and more data becomes available.

Assessment for Developing Countries : Useful for providing estimate of plantation requirements to meet markets. Operates on sample data, but requires sophisticated computing capacity. An aid also to planning industry establishment. Predictor functions are not an integral part of model, and can be altered easily. Simulation model provides much useful information and can be used alone for predicting volumes.

Optimisation Model 3

"MASH"

Organisation : Forests Commission Victoria,
601 Bourke Street, Melbourne, Victoria 3001.

Information : R.B. Smith.

Forest : 120,000 ha of regrowth forest predominantly **E.regnans** and **E.delegatensis** principally 1939 origin.

Objective : To define the cutting schedule that maximises the present net worth of the wood resource, subject to woodflow constraints.

Time Span : Up to 100 years.

Input : Stand data including diameter distribution, thinning strategy, road and transport costs, royalty values, harvesting constraints.

Algorithm : Parametric linear programming, to maximise the present net worth subject to constraints on wood flows. MASH incorporated several features of STANDSIM.

Output : Optimal cutting strategy and wood flows, cash flows and present net worth associated with that strategy.

Application : The definition of sustainable woodflow levels, supply area and broad harvesting strategies.

Evaluation in Organisation : The technique has been successful in broad applications over the resource as a whole. There are problems with further application at district level because of change of staff and computing environment and intricate rules for operating the model.

Assessment for Developing Countries : MASH would be a useful aid in planning the management of a forest of complex structure with respect to age, density, site quality and species. Depends on good inventory and this may be a drawback. Also requires sophisticated computing system, which may be a difficulty in applying MASH to developing countries.

Reference : Weir, I.C.A. 1972. Planning of wood production using systems analysis. APPITA 26 (2) : 107-112.

LITERATURE CITED

Johnson, K.N., and Scheurman. 1977. Techniques for prescribing optimal timber harvest and investment under different objectives--discussion and synthesis. Forest Science Monograph 18.

Ware, K.O., and J.L. Clutter. 1971. A mathematical programming system for the management of industrial forests. Forest Science 17(4):428-45.

Operations Research Techniques in the Management of Large-Scale Reforestation Programs

Joseph Buongiorno D.E. Teeguarden

Abstract: A reforestation planning system for the Douglas-fir region of the Western United States is described. Part of the system is a simulation model to predict plantation growth and to determine economic thinning regimes and rotation ages as a function of site characteristics, initial density, reforestation costs, and management constraints. A second model estimates the expected value of alternative reforestation projects and determines the optimum allocation of scarce resources to these projects via linear programming. The applicability of the system to developing countries is briefly considered.

INTRODUCTION

This paper describes a system of computer programs developed by the authors to assist in the design and selection of reforestation projects. Given an initial set of resource and policy constraints, the system permits managers to select the set of reforestation projects to execute, the method of reforestation to employ, and the initial stocking in new plantations. The system was developed for use by managers of large-scale, public land reforestation programs in the Douglas-fir region of the Western United States. A more technical and detailed description of the system, as well as a discussion of the economic principles on which it is based, can be found in Buongiorno and Teeguarden (1973).

Problem Definition

Every year during the months of July and August, the reforestation staff of each district of the U.S. Department of Interior, Bureau of Land Management (BLM) in Western Oregon receives a commitment of funds, seeds, and seedlings, from the State Director. Given the limited amount of resources and the available land, the reforestation plan which best satisfies BLM goals must be prepared. The model is designed to answer, for each tract of land available for reforestation, the following interrelated questions:

How many acres should be reforested?

What site preparation should be applied?

Is it better to plant or seed?

How many trees, or pounds of seed, per acre should be used?

From what sources can necessary seeds or seedlings be obtained?

Management Objectives

It was determined that the Bureau of Land Management guidelines are consistent with the objective of maximizing present net worth (PNW), under constraints. Some constraints are explicitly stated, e.g., minimum rotation age allowed on BLM lands, minimum number of trees to be maintained on thinned plantations, minimum commercial volume extracted from thinning operations. Other constraints are implicit. These are reflected by the system of accounting, or by the shadow prices used in PNW computations. These prices may, and often should, differ from market prices, which cannot be the only basis for public project evaluation, although they may be very useful indicators of the supply and demand of reforestation inputs and outputs.

System Overview

The reforestation planning system is composed of two main computing programs named FOREST and REGEN (fig. 1). FOREST is a simulation model capable of predicting the growth of Douglas-fir plantations as a function of site quality and initial density. FOREST also includes optimization algorithms which allow for the determination of optimum thinning regimes, and optimum rotation ages, as a function of site quality, initial density, and reforestation costs, given the objective of maximizing PNW, under constraints. The results obtained from program FOREST are part of the input in program REGEN. This second program determines the expected PNW of reforestation alternatives applied to the various tracts of land available. The program also generates and solves a linear programming model which describes the interaction of all projects competing for a limited budget, and limited stocks of seed and seedlings. The program FINAL simply displays the solution in a form readily understandable by reforestation managers.

FOREST: A SIMULATION MODEL FOR MAN-MADE FOREST MANAGEMENT

As indicated earlier, PNW maximization, under constraints, is the guide to making plantation investment decisions. FOREST applies this principle in deriving estimates of future plantation yields. The management decisions considered by FOREST are (1) initial densities in plantations, (2) schedule of intermediate cuttings as the plantation matures, (3) rotation age. The final output of FOREST is a set of yield tables (fig. 2) showing the expected PNW of a plantation as a function of site index, initial density of the plantation, and establishment costs. PNW is always computed assuming that an optimum thinning regime and rotation age will be applied to the plantation, within policy constraints specified by the manager.

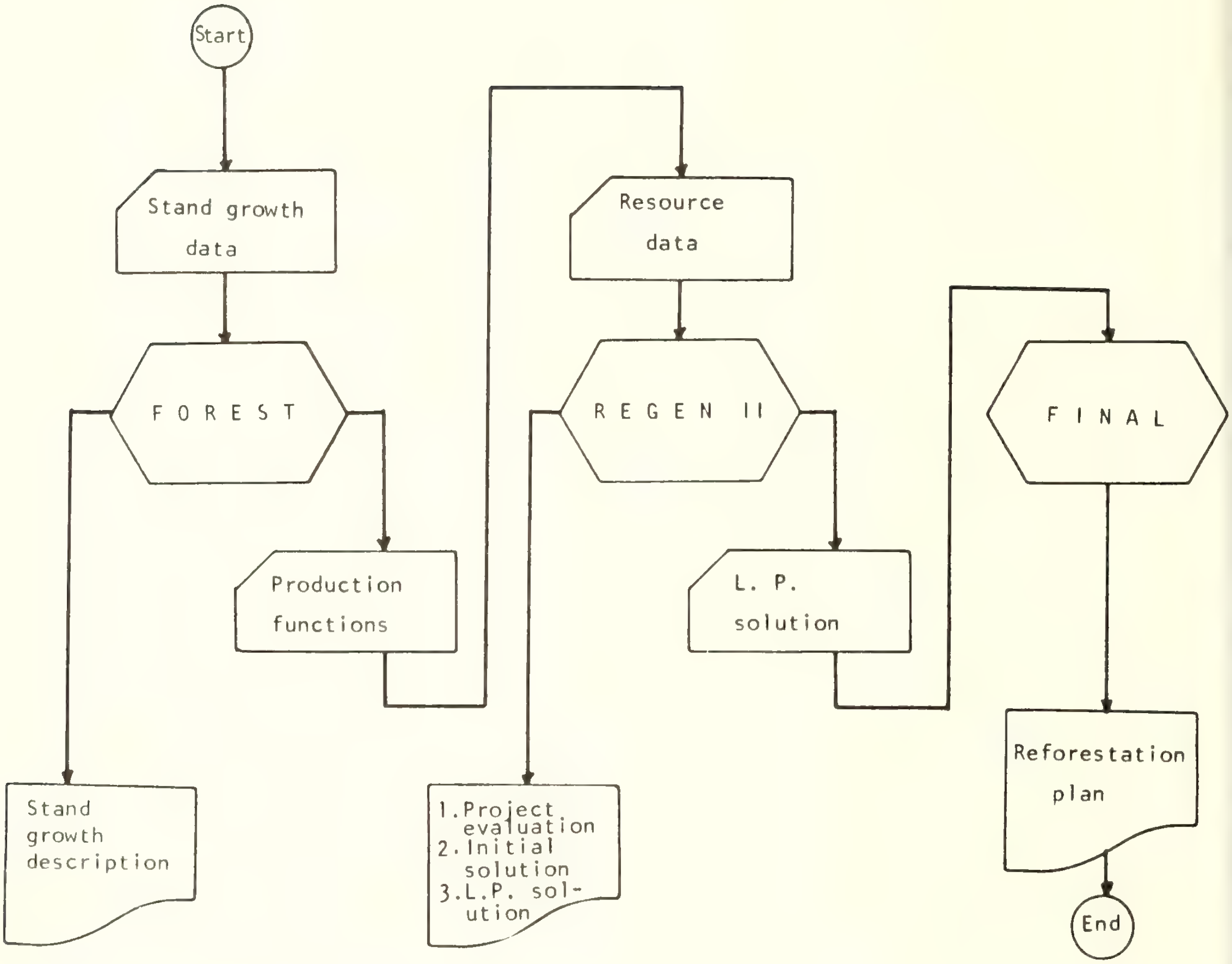

Figure 1. Elements of the reforestation planning system.

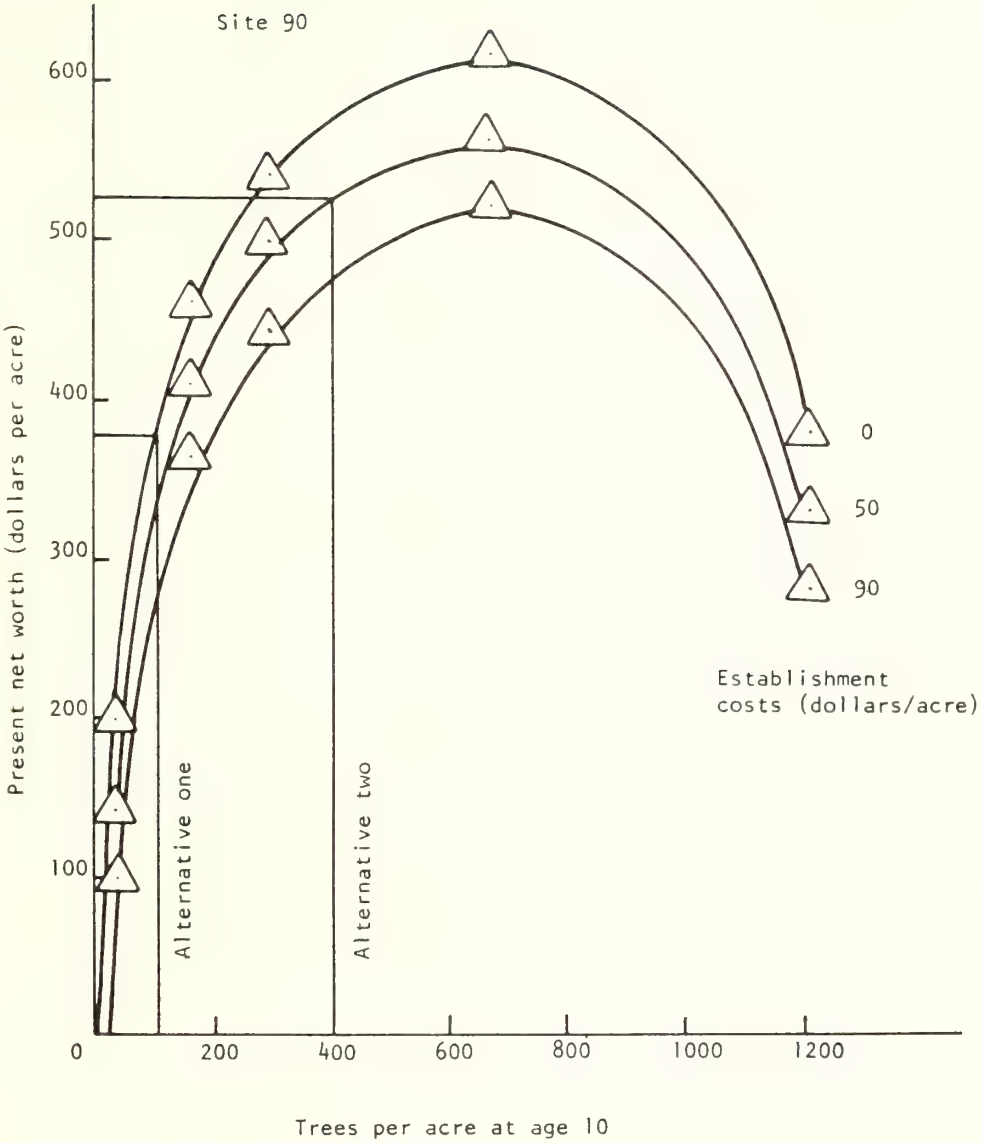

Figure 2. Present net worth of reforestation alternatives.

FOREST is composed of two basic elements. The first one simulates the growth of an even-aged stand of Douglas-fir trees. The second element models the decisionmaking process (thinning regime, and final harvest). Stand growth is determined by modeling the behavior of individual trees. Individual tree growth is computed as a function of tree age, and competition from neighboring trees, using deterministic functions. Individual tree mortality is instead a random process in which the probability of death, within a specific time span, is a function of tree age, site index, and competition. Figure 3 shows the behavior of entire stands, as predicted by FOREST, for three different initial densities, when no thinning is applied.

The decisionmaking element of FOREST is designed to apply a thinning regime which maintains an optimum stocking in plantations, i.e., a stocking such that the marginal value growth of the stand will be equal to the guiding rate of interest used. Managerial constraints regarding the minimum volume of thinnings which should be extracted, and the minimum number of trees remaining after a thinning operation, may also be specified. Thinning regimes obtained from FOREST have often doubled the PNW of plantations. FOREST determines the age of final harvest by maximizing soil rent, but longer rotations may be specified by the user.

REGEN: A MODEL FOR PROJECT ANALYSIS AND RESOURCE ALLOCATION IN REFORESTATION PROGRAMMING

This model is designed to find the set of reforestation activities which yield the plan of maximum PNW in a given year. This is done by defining the set of available alternatives and by representing mathematically the interaction of all alternatives in their use of common resources.

When a tract of land is reforested, the following alternatives are available: (1) the tract can be partially reforested, (2) the tract can be seeded or planted, (3) before seeding or planting, the site can be prepared in different ways, (4) planting or seeding can be carried at alternative densities, (5) the tract can be reforested from seeds or seedlings originating from different zone-elevation classes.

The first set of operations in REGEN determines the expected PNW of each available alternative, assuming all resources would be available to execute them. This is done from the yield functions resulting from FOREST (fig. 2), and from other data describing the characteristics of each tract available for reforestation (including location, brush cover, slope, area, site, current stocking, etc.), as well as the alternative reforestation techniques to be considered, and their respective cost. From these data REGEN determines the expected survival in plantations, and the expected PNW of each alternative. At this stage, a simple ranking of alternatives may yield the optimum program if no resource, or a single resource, is constraining. The ranking criterion used by REGEN may be PNW per acre, or PNW per dollar of available budget, or PNW per pound of seed or per seedling, depending upon the constraining resource. In general, however, several resources are constraining. The problem of determining the optimum reforestation plan then takes the form of a linear program

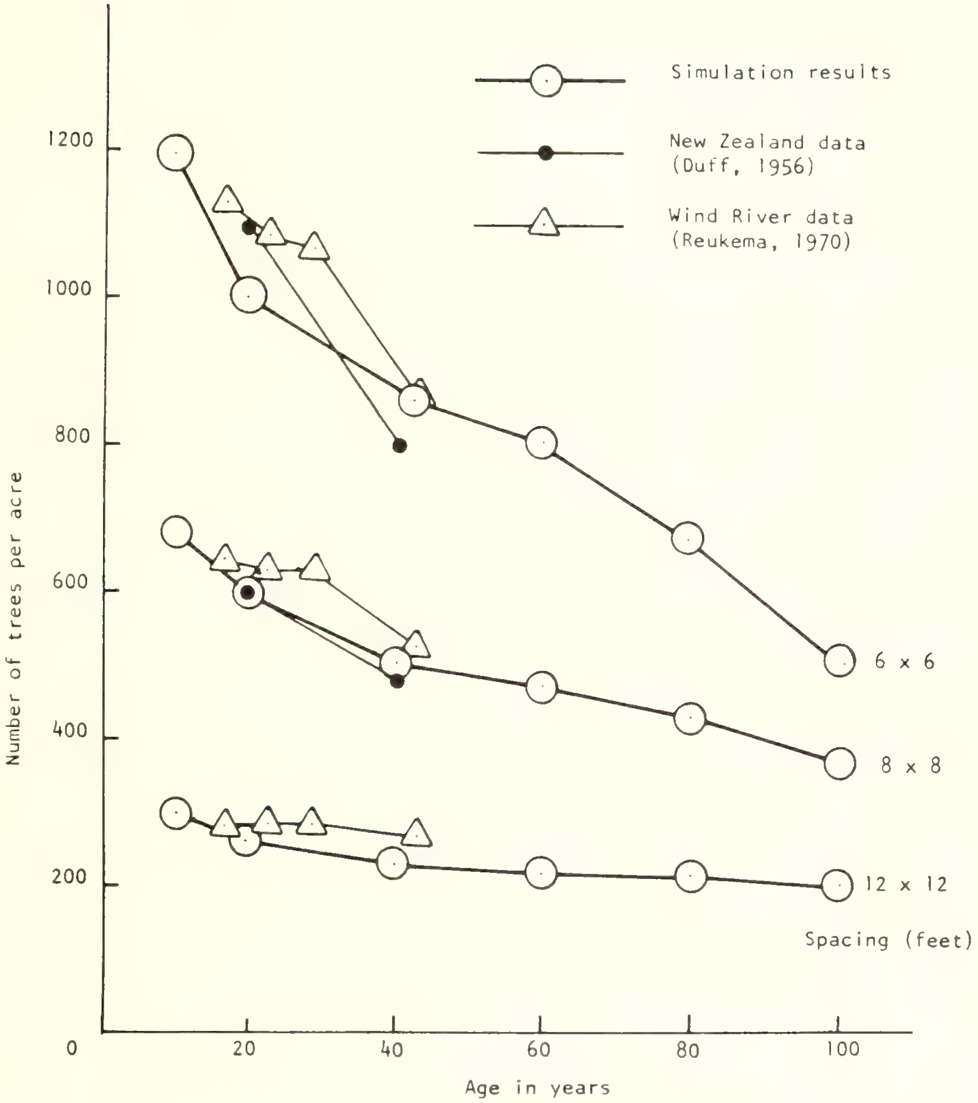

Figure 3. Predicted and observed survival in plantations.

in which the objective function is the total expected PNW of the plan, while the constraints specify that (1) the stocks of seeds and seedlings originating from each zone-elevation class, (2) the available budget, and (3) the land area on each tract cannot be exceeded. This large linear program is generated and solved automatically by REGEN, using user-supplied data on the amounts of resources available. The FINAL program lists all projects recommended for reforestation in the current year, method of treatment, seedling density or original spacing in plantations scheduled for hand planting, budget requirements, and quantity and origin of seed and seedlings stock.

CONCLUSIONS AND POTENTIAL FOR DEVELOPING COUNTRIES

It has been found in applications that the system presented here may yield reforestation plans whose PNW is 25% higher than what would be obtained by using simple ranking criteria (e.g., benefit/cost ratios). The gain with respect to traditional rules of thumb may be more important. However, such comparisons assume that the assumptions underlying the system, in particular the system of shadow prices used, are correct. The reforestation technicians liked the system's simplicity. In particular, it requires little input. A single data card is sufficient to describe each tract available for reforestation. Furthermore, the required input is readily available from reforestation records. Nevertheless, the system ran into implementation hurdles; the main one being that data were prepared by field foresters, while programs were run at headquarters. The availability of remote terminals at field stations should decrease this problem.

We believe that the basic methodology should find applications in developing countries. The program FOREST in particular should be useful in determining the economic effect of varying initial density in plantations, in computing economic thinning regimes and rotation ages, and in determining the economic feasiblity of man-made forests. Naturally, the growth functions used in the program would have to be calibrated to reflect each specific site and species combination. Often this will require some informed guessing. The program REGEN may have more limited applications as it was tailored to the situation faced by the Bureau of Land Management in southwestern Oregon. In other reforestation projects, limiting resources may be very different; however, the principles of evaluating all alternatives and allocating resources optimally remain universal. Determining appropriate shadow prices for plantation products, interest rates, wage rates, and other inputs will be a very important step in a developing country, where market prices are unlikely to reflect adequately all the objectives of a reforestation project (FAO 1974).

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TRACT      ZONE-ELEV.      TREATMENT      DENSITY      AREA

XXXXX      XXXXXXXXX       XXXXXXXXX      XXXXXXX      XXXX

001            1               1             3         8.03

001            1               1             4         1.97

002            1               3             1        20.00

SEEDLINGS FROM ZONE-ELEV.        1      QUANTITY =        1000.00

SEEDLINGS FROM ZONE-ELEV.       11      QUANTITY =        2000.00

SEEDS     FROM ZONE-ELEV.       11      QUANTITY =          15.00

003             2              3             1        40.00

003             2              3             2        10.00

SEEDS     FROM ZONE-ELEV.        2      QUANTITY =          30.00

SEEDS     FROM ZONE-ELEV.       11      QUANTITY =          15.00

TOTAL AREA =       80.0
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Figure 4. Example of a small reforestation plan, as displayed by subroutine FINAL.

LITERATURE CITED

Buongiorno, J. and D.E. Teeguarden. 1973. An economic model for selecting Douglas-fir reforestation projects. Hilgardia 42(3):35-120.

Duff, G. 1956. Yield of unthinned Douglas-fir, Corsican pine, and ponderosa pine in New Zealand. For. Res. Notes. New Zealand Forest Serv., Wellington.

Food and Agriculture Organization of the United Nations. 1974. An introduction to planning forestry development projects. FAO/SWE/TF118. FAO, Rome.

Reukema, D.L. 1970. Forty-year development of Douglas-fir stands planted at various spacings. USDA Forest Service Res. Paper PNW-100, 21 p., illus. Pacific Northwest Forest and Range Exp. Stn., Portland, Oreg.

Wood Transportation Systems—A Spin-Off of a Computerized Information and Mapping Technique

William W. Phillips Thomas J. Corcoran

Abstract: A computerized mapping system originally developed for planning the control of the spruce budworm in Maine has been extended into a tool for planning road network development and optimizing transportation costs. A budgetary process and a mathematical linear programming routine are used interactively with the mapping and information retrieval capabilities of the system to determine the allocation and association of wood sources and markets.

INTRODUCTION

In December 1975, a short term project (see Appendix) was completed that allowed the computerized mapping of locations and levels of spruce budworm infestation in Maine. This conformed to a sampling system employed by state officials whereby data on infestation was taken periodically by a series of sample units each equal to an area of approximately 600 acres. Each unit became the basis for a data (information) point and it became clear that the mapping routine offers potential well beyond its original intent. It is currently in use for the annual state budworm survey (Simmons and others 1976).

Besides the opportunity for additional informational overlays beyond budworm infestation indices, the relational properties of each unit to another possessed the potential to be mathematically manipulated, thus allowing location strategies of wood origins and potential markets to be correlated very accurately and rapidly. Transportation phenomena is the focus of the correlation. Existing road networks have been visually and mathematically related to data points. Specific requirements for new roads are integrated onto the overall system, and transportation and handling cost formula are available to interpret wood movements strategies in terms of a definable optimum. The system is designed to be open-ended in regard to this formulization so as to allow logical choices as to appropriate cost components. Algorithms for selecting applicable cost configurations depending on the trafficability of various road classes and/or transportation means (trucking or rail) have been developed within a framework of resource available and consumption requirements. Mathematical programming offered high potential for selection of optimal transportation strategies. These strategies involved not only specifics on the movement of wood, but also priority criteria for the resource areas on which to concentrate harvesting efforts when large wood surpluses are in excess of short-term market needs.

The budgetary process as well as the mathematical programming routine is directly interactive with the mapping and information retrieval system, and is designed to be a sub-system to the overall system. Aspects of costing in any category of operating expenses for transportation or handling and those expenses relating to new roads can be included in the whole system and are relatable to data points. Existing road networks are known by the system and also referenced to specific data points where information on trafficability, etc., can be stored. Travel patterns are developed by summarizing data points between any combination of wood origins and wood destinations which are themselves merely data points. Preliminary estimates indicate that the accuracy in measures of various forms of distance exceeds the probable accuracy of maps from which data point references were established. New roads are hypothetically constructed between appropriate wood origins and existing roads by logical rules internally maintained by the computer system. Rapid and precise evaluations can then be made for given market transport possibilities when periodical levels and locations of available wood and of market requirements are offered to the system. Optimal strategies can be made available directly from this system, which allows ready updating of information on any data point and selection of modes in costing suitable to the planner.

The methodology suggested may well have wider application beyond Maine, possibly on a regional basis or for other state or provincial areas in North America. The techniques are structured so that implementation elsewhere can readily be facilitated and not necessitate a new total effort.

THE TRANSPORTATION SPIN-OFF

Since the spacial arrangement of wood origins, wood markets, and transportation networks can be determined from the data organized by map location, it is possible to automatically develop transportation routes from each wood origin (source) to each wood market (destination), where each of these is represented by a map data point. Transportation routes are developed so as to minimize transportation costs; they assume cost linearity (that is, the cost from A to C through B equals the cost from A to B plus the cost from B to C).

The transportation cost is composed of two elements--the cost of building new roads (or transportation networks) and the unit cost of transporting the material over the transportation network. New roads are generally costly both to build and maintain; therefore, in developing routes, a goal is to approach a minimum of new road construction. This is accomplished by a two-pass computer processing of source points. During the first pass, the closest road is located through an outward scanning of surrounding data points and the straight line distance to this road is calculated. The source points are then sorted for reprocessing such that those points closest to a road are processed first. During the second pass, another search for the closest road is made. When it is located, a hypothetical new road connecting the source point with the road is added to the map road system by the computer program. This hypothetical road then becomes available to subsequent source point processing. Although this method does not necessarily yield an absolute minimum amount of new road construction, it should closely approximate the minimum.

With roads to each source point, minimum transportation cost from each source point to each destination can be calculated. Computer scanning of map data allows transportation networks to be followed. Starting from a destination point and successively adding the cost of transporting to all adjacent road points, a transportation cost to the destination is determined for all road points including all source points. Always extending from the least cost end first produces minimum cost values with a single scanning of road points. The cost of transporting to an adjacent point can either be based on a function of distance (as determined from the geometry of the area represented by a data point), or with known costs of traversing a particular area, can be uniquely specified for each point and thus can include trafficability factors-- e.g., road quality, average speed, and traffic load.

Following these methods, the cost of transporting from all source points to all destination points is determined. This information, combined with data on wood volumes available at each source and the requirements at each market, is fed into a linear programming transportation model to determine allocation and association of wood sources and markets.

BACKGROUND INFORMATION

The extent and importance of the wood-using industries in Maine can be sumarized (for 1973) as follows:

(1) Three out of ten Maine workers are employed in the wood-using industries.

(2) The industries ranked first in value of manufactured product (1.3 billion dollars).

(3) Eighty-six percent of Maine's land area is in commercial forests (17 million acres).

(4) A total of 3.14 million cords of pulpwood was harvested, with 56% of this in spruce-fir. For sawlog harvest, the total was 354 million board feet, with 57% in spruce-fir.

Approximately one-third of the State's forest area is currently under the threat of spruce budworm devastation. The epidemic can be expected to produce high mortality, particularly in balsam fir and to a lesser degree in spruce, if adequate control measures are not forthcoming. Trees that succumb to the insects' attack must be harvested within a two- or three-year period or the physical deterioration of the wood will be too advanced to allow its commercial use. The timing of a planning effort becomes more critical considering that the area represented to be approaching an epidemic stage contains, at a minimum, a twelve-year supply at Maine's current wood consumption levels.

Under normal harvesting procedures, species present in a forest stand with fir and spruce, and not affected by the budworm, would also have to be removed with economical wood handling and transportation methods.

Preliminary study by the Corps of Engineers on the feasibility of a major hydroelectric project in Maine was begun this past year. The associated dam and its head waters will take out of production thousands of acres of Maine's timberlands. Agents of the Corps of Engineers have already contacted this investigator for estimates on the market potential of salvaged timber and for information on harvesting-transportation problems relating to the salvage. These estimates represent only preliminary appraisals; actual planning will eventually be required if the timber area is to contribute effectively to this State's wood resource requirements.

Considering the potential for an evaluation system such as those discussed here, at least three areas of immediate concern are benefited. These include planning in regard to wood flow within the region:

(1) As typical yearly wood consumption patterns are encountered.

(2) As wood surplus resulting from budworm devastation occur.

(3) As timber area losses in hydroelectric development are considered.

The need to expand the opportunities for systematic evaluation of wood movement strategies is most timely as the concerns for wood utilization, especially in light of the budworm and the hydroelectric development, are and will surely remain key issues in the State of Maine, in New England, and in Eastern Canada for the remaining years of this decade.

Models developed from the proposed investigation are not intended to be useful solely in the shortterm, as suggested by problems like the budworm and developments that affect large forest acreages, nor will they necessarily remain local in the spread of their use. Their nature fully dictates that they can find application in the evaluation of transportation aspects inherent in marketing strategies of a long-term nature. The techniques utilized, if not the data structures, should prove of value to other regions as well.

PREVIOUS STUDIES

Past efforts of a statewide scope have proved fruitful in understanding wood distribution and the means thereof (Corcoran 1964, Schroeder and Corcoran 1965, Corcoran and others 1966). These particularly focused on truck-supported wood movements and included not only descriptive information but system planning pertinent to the times. Forest road location theory continues to be advanced (Ashley and others 1973, Corcoran 1973). Appraisals of the current situation are available in regard to enterprises that produce Maine's wood supply (Corcoran and Sarna 1973), to computer-based mapping routines (Phillips and others 1976) and to export market potential (Corcoran 1976). Wood movement strategies have also been explored in regard to general models for regional applications (Holland and Judge 1962, Thompson and others 1968, Anderssen 1971) and to the budgetary planning of a single firm (Bartelheimer 1973, Sowell and others 1975, Newham 1975, Wimble 1975, Bailey 1973). Mapping by computer has found favor in recent years (Harding 1973, Nez 1971) especially for visual descriptions of use patterns, vegetative cover, and urban planning schemes. However, those for the most part were subjective in nature and have not taken advantage of mathematical potential inherent in a computer-based system. Numerous other works could be listed that are commonly known and well documented in established computer bibliographies on operation-research (Martin and Sudak 1973, Field 1974) and on the budworm itself (Corcoran and Simmons 1975). Information systems and decision theory have been explored by many authors within a workshop format (Stone and Ware 1971) and in a publication supporting needs for an information bank (Wolf 1970). Information systems pertaining to Maine have received international attention (Corcoran and Simmons 1976, Corcoran 1976).

APPENDIX

Effective planning for control of the spruce budworm in Maine requires knowledge of the distribution of the budworm as well as the condition and susceptibility of the trees in the areas of infestation. Currently, a hazard rating based on sample measurements of such factors as previous damage, current defoliation, tree vigor, and egg mass density is calculated for various localities throughout the state. A map of the state showing the location and hazard rating of each of the sampled points is prepared and areas of infestation are marked. These provide a visual indication of the distribution of budworm threat to the forests of Maine, and allow planning of such activities as spraying and salvage.

In order to facilitate the production of these maps, a computer program has been developed which will produce maps of the state on a computer line printer. The state is divided into small sections corresponding to the state fire control divisions. These sections are subdivisions of the U.S Geological Survey 15-minute quadrangle maps and are found by dividing each of the U.S.G.S. maps into 9 blocks and each block into 25 sections, each 1 minute by 1 minute. Thus a section is 1/225th of a U.S.G.S. quadrangle and covers approximately 591 acres.

A two-dimensional array is allocated within the program storage with each cell corresponding to one of the sections of the state. The section of the state in which the sample was taken, along with the data collected, is fed into the program. The rather complex designation of U.S.G.S. quadrangle, block, and section used in the field is converted by the program into a two-value designation indicating the row and column of the section within the state and thus the cell of the array corresponding to the location. This simplification allows adjacent cells to be easily determined and examined. The program calculates the hazard rating from the data and stores the computed value in the appropriate cell within the array. Both the array of computed hazard ratings and the original data for additions and further analysis can be saved.

From the data stored in the array, requests can be made to print all or portions of the state. Increasing integer digits indicate increased hazard value. Cells which fall inside the state boundary are distinguished from those that do not. This allows the portions of the state not sampled to be indicated by a printed character or characters while areas outside the state are void of such characters.

The size of the map produced may be varied by specifying a scaling factor. The smallest (largest scale) map produced uses one character to represent a single section. This map is approximately 27 inches wide by 34 inches long when the entire state is printed. Because the spacing on a printer is relatively fixed, the small map distorts the state slightly, making it an average of 14% wider than it should be. For most applications, this level of distortion presents no problems since a general feeling for spatial distribution is the primary goal. Specific locations can be determined from grid coordinates and the U.S.G.S. maps if required. The distortion can be virtually eliminated if a larger map is formed using multiple characters to represent one section. This could have the additional benefit of allowing more than one piece of information about a sector to be printed on a map. Any of these maps may, of course, be reduced to a more convenient size through photoreduction techniques.

Although the current program would only replace the manual system being used at present, several factors make this system more desirable. One is the speed with which maps can be produced. This will allow the production of preliminary maps as the data is collected. These could then be used to help define areas which require more sampling to delineate spray, salvage or other boundaries.

Another factor is the capability for future expansion existing in the system. Among some of the more interesting possibilities are extensions which would allow any specified linear combination of the current or previous year's hazard rating factors to be mapped. This could be used to compare visually the distribution of such factors as previous damage and current infestation level, which might provide insight into changing trends in infestation. Comparisons of linear combinations of current and previous year's samples might be used to refine the formula used to compute the hazard rating. Another possibility for extension is the inclusion of fixed information about a section. Such information as forest cover type might be used to modify the hazard rating. The inclusion of information on road networks and market locations would be used to determine the most economical and efficient salvage locations and transportation routes in the event of high losses.

A second potential capability is use of the system to display a variety of other forest-related surveys. Other forest insects and forest diseases could be mapped annually from annual survey data. Annual tree mortality data could be mapped as well as forest age data or, for that matter, any resource data base covering the state or portions of the state. Such a system might eventually form the basis of a general resource data base display system for the entire state of Maine.

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LITERATURE CITED

Anderssen, Stig. 1971. Long-range planning of forest operations. Skogsarbaten Ekonomi 2E 1971. Stockholm, Sweden. 8 p.

Ashley, Marshall D., Thomas J. Corcoran, and James C. Whittaker. 1973. Remote sensing modifications for optimized logging road networks. ASAE Trans. 16(6):1044-1047.

Bailey, G.R. 1973. Wood allocation by dynamic programming. Can. Forest Serv. Publ. 1321. 19 p.

Bartelheimer, P. 1973. A model for the cooperation of a forest enterprise with a wood processing firm. In Proc. 1973 Plann. Control Symp., Int. Union Forest Res. Org., [Frieburg, Germany]. 9 p.

Corcoran, Thomas J. 1964. Scheduling of pallet trucks in pulpwood operations, a linear programming application. Maine Agric. Exp. Stn. Tech. Bull. T-7, 22 p.

Corcoran, Thomas J. 1973. A FORTRAN program for spacing optimization of logging roads and landings under flatland assumptions. Sch. Forest Resour. Univ. Maine, Orono. Tech. Note 56, 13 p.

Corcoran, T.J. 1976. A briefing on the Scandinavian scene and its markets. 19 p. Amer. Pulpwood Assoc. 76-P, Washington, D.C.

Corcoran, T.J. 1976. Information retrieval systems and a technical association's need for dynamic information on wood-producing organizations. Proc. 16th Cong., Div. 3-CG4, Int. Union Forest Res. Org. [Oslo, Norway, June 20-25, 1976], 7 p.

Corcoran, Thomas J., and Rudolph P. Sarna. 1975. Wood producer survey and an information system. 24 p. Amer. Pulpwood Assoc. Paper 76-P-2, Washington, D.C.

Corcoran, Thomas J., D. Schroeder, and D. Thompson. 1966. An evaluation of the distribution of trucked pulpwood in east-central Maine - a linear programming application. Maine Agric. Exp. Stn. Bull. 640, 11 p.

Corcoran, T.J., and G. Simmons. 1975. A computer-based bibliography on spruce budworm. Sch. Forest Resour., Univ. Maine, Orono.

Corcoran, T.J., and G.A. Simmons. 1976. A map-based computer storage and retrieval system for state-wide information on spruce budworm infestations and marketing opportunities from resulting timber mortality areas. Proc. 16th Cong., Div. 3-CG4, Int. Union Forest Res. Org. [Oslo, Norway, June 20-25, 1976], 7 p.

Field, D.B. 1974. Applications of operations research to quantitative decision problems in forestry and the forest industries--a bibliography. Yale University, Sch. For. Environ. Stud. 30 p.

Harding, R.A. 1973. GRIDS works for DNR. Dep. Nat. Resour. Rep. 25, State of Wash. 48 p.

Holland, I.I., and G.G. Judge. 1962. The spacial structure of the lumber industry: estimated interregional flows and price differentials. Univ. Ill. Res. Rep. AERR-52, 41 p.

Martin, A.J., and P.E. Sudak. 1973. Operation research in forestry - a bibliography. USDA Forest Serv. Gen. Tech. Rep. NE-8, 90 p. Northeastern Forest Exp. Stn., Broomall, Pa.

Newham, R.M. 1975. LOGPLAN - a model for planning logging operations. 59 p. Forest Manuf. Inst. Inf. Rep. FMR-X-77. Ottawa, Ontario.

Nez, George. 1971. A composite mapping system for practical location research. Off. Plann. Program Support, Econ. Dev. Adm., Commerce Dep., Wash., D.C. 31 p.

Phillips, W., G. Simmons, and T. Corcoran. 1976. Spruce budworm and a computer-based mapping and information retrieval system. Maine Forest Rev. 9:13-15.

Schroeder, D., and Thomas J. Corcoran. 1965. Distribution patterns for pulpwood harvested in east-central Maine. Maine Agric. Exp. Stn. Bull. 630, 44 p.

Simmons, G.A., W. Phillips, and T. Corcoran. 1976. Computer mapping and processing spruce budworm survey and related data--1974 and 1975. 16 p. Amer. Pulpwood Assoc. Paper 76-P-8, Washington, D.C.

Sowell, R.S., T.J. Corcoran, and A.W. Anderson. 1975. Mathematical programming system (MPS/360) - concept and applications. ASAE Trans. 18(3):591-595.

Stone, R.N., and K.D. Ware (ed). 1971. Computer and information systems in resource management decisions. In Proc. USDA Forest Serv. and Coop. State Res. Serv., [Wash., D.C. July, 1971], 130 p.

Thompson, E.F., W.B. Tilghman, P.H. Hoephner, and D.P. Richards. 1968. Linear programming over time to establish least-cost wood procurement procedures. Va. Polytech. Inst. Res. Div., Bull. 29, 70 p.

Wimble, A.W. 1975. The development of a hypothetical linear programming model for the analysis of whole tree chips. In Financial management of forest resources. [Proc., Sem. New Orleans, Louisiana], 21 p.

Wolf, Charles H. 1970. A study of plant location procedures and the need for a data bank in West Virginia. Appalach. Center Res. Series 15. 96 p.

Optimal Control of Raw Timber Production Processes

Ivan Kolenka

Abstract: This paper demonstrates the possibility of optimal planning and control of timber harvesting activities with mathematical optimization models.

The separate phases of timber harvesting are represented by coordinated models which can be used to select the optimal decision for the execution of any given phase. The models form a system whose components are connected and controlled by means of information flows.

A mathematical model is presented for the optimal planning of harvesting activities for the forest enterprise. The use of a mathematical model contributes to the balancing of supply and demand, to the coordination of forest management plans with other activities of the national economy, and finally, to the minimization of production costs.

INTRODUCTION

Planning in Czechoslovak forestry has a long tradition, and is highly developed. The present stage of development of the society imposes demands on the planning and control of production processes in the form of requirements for maximum utilization of production sources and for meeting the demands of the society. In the process of planning and control it is necessary to follow the efficiency principle which states that (a) the planned yield must be obtained at the lowest cost or effort, or conversely that (b) the highest yield is to be obtained from given resources.

This type of planning and control requires a well-elaborated information and decision system, and the use of advanced techniques for the transfer and processing of information.

PROBLEMS

In this paper I shall deal with the processes of decision in planning and control of harvesting, and point out the possibilities of utilizing the optimization models of operational research for the selection of the planning alternatives.

The harvesting of timber, in the context of Czechoslovak forestry, represents a complex system and requires the solution of several problems. Each country has its specific conditions and requires a different approach to the formulation of the task. Generally, it is necessary to recognize that mathematical models cannot be based upon the principles of maximum utilization of the forest for this would result in the decrease of its permanent production capacity and would simultaneously affect the biological balance adversely. With long-term planning models it is necessary to consider this principle in the formulation of the mathematical model. In short-term models, this principle is observed by insuring that the forest management plan (decennial plan) is constructed so as not to allow the decrease of the production potential of the forest.

The harvesting of timber is divided into felling, gathering at landings, primary conversion (production of wood assortments), and hauling of timber. The structure of the harvesting process is illustrated in figure 1. Each stage of timber production is represented by coordinated models leading to the selection of the optimal decision at a given stage.

The models form a system of components connected by information flow in such a way that the output from one model represents an input into a "lower" model. To date some of the mathematical models have been used in planning (e.g., optimal control of timber hauling); others have been theoretically validated or are in the process of being tested.

MODEL FOR SHORT-TERM PLANNING OF HARVESTING ACTIVITIES

The model solves the problem of optimal scheduling of quarterly harvesting activities, and of controlling the management of the "gravitational" areas of forest enterprises. "Gravitational" areas consist of a collection of stands which form a contiguous area and which have approximately the same production conditions. The annual tasks in each stand are given by the forest management plan, and the sum of these tasks represents the annual tasks for the gravitational area.

The mathematical model for short-term planning of cutting activities must fulfill the following conditions:

Coordinate sustained harvesting activities with the demand for timber assortments as specified by contracts between supplier and customers

Recognize the limited availability of labor

Take into account the capacity of landings with respect to the logging techniques available for gathering timber at landings

Concentrate as much as possible the harvesting and the silvicultural activities in each gravitational area

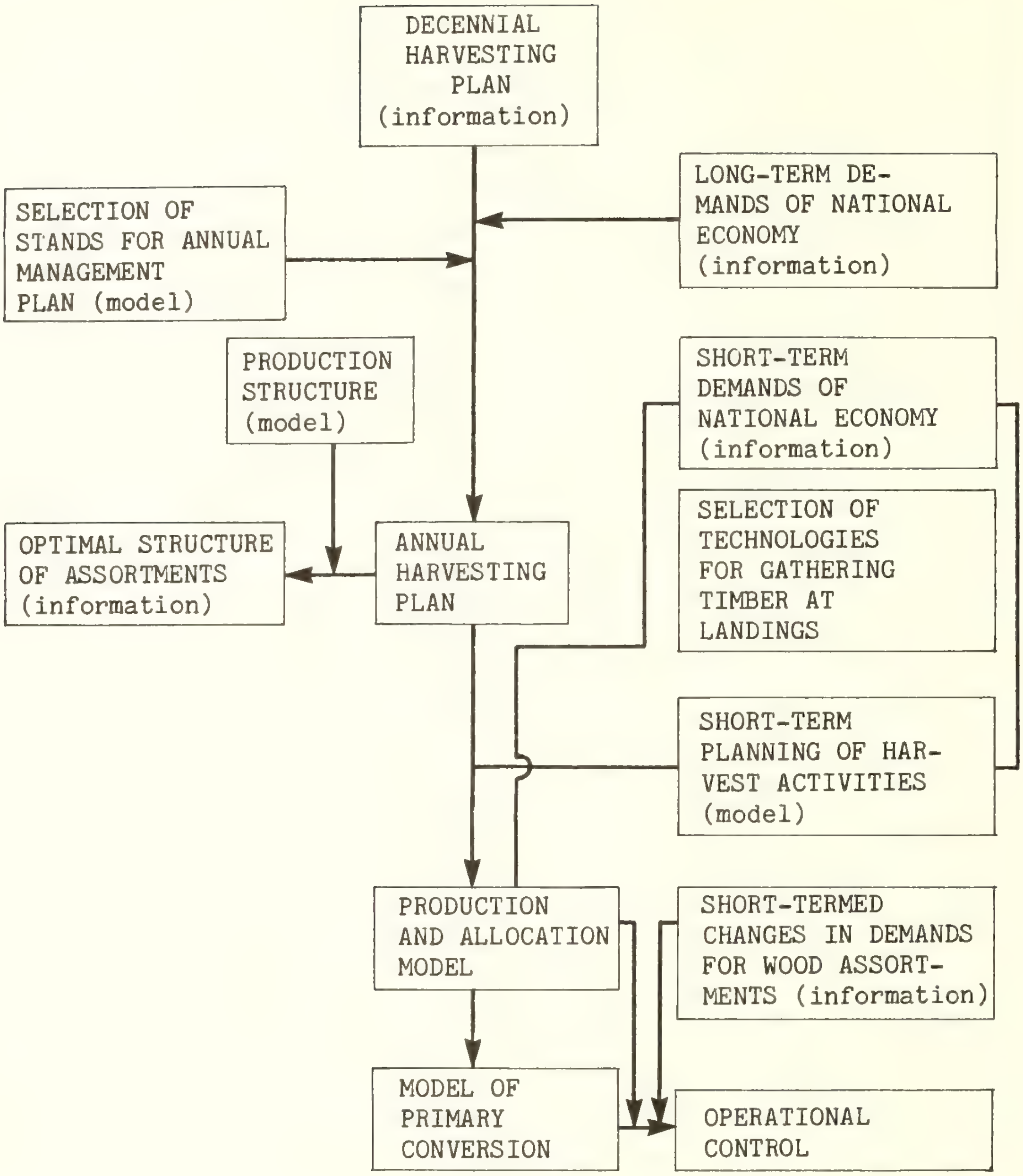
DECENNIAL HARVESTING PLAN (information)
LONG-TERM DEMANDS OF NATIONAL ECONOMY (information)
SELECTION OF STANDS FOR ANNUAL MANAGEMENT PLAN (model)
PRODUCTION STRUCTURE (model)
SHORT-TERM DEMANDS OF NATIONAL ECONOMY (information)
OPTIMAL STRUCTURE OF ASSORTMENTS (information)
ANNUAL HARVESTING PLAN
SELECTION OF TECHNOLOGIES FOR GATHERING TIMBER AT LANDINGS
SHORT-TERM PLANNING OF HARVEST ACTIVITIES (model)
PRODUCTION AND ALLOCATION MODEL
SHORT-TERMED CHANGES IN DEMANDS FOR WOOD ASSORTMENTS (information)
MODEL OF PRIMARY CONVERSION
OPERATIONAL CONTROL

Figure 1--Structure of the timber harvesting process.

Elaborate quarterly plans which minimize the costs of harvesting and of other management activities.

This task can be formulated as a linear programming model:

$$\text{Minimize } z = \Sigma_{ijk}\ g_{ijk} \cdot x_{ijk} + \Sigma_{ijp}\ r_{ijp} \cdot y_{ijp} + \Sigma_{ijl}\ u_{ijl} \cdot z_{ijl}$$

$\Sigma_i\ x_{ijk} = a_{jk}$ for $j = 1, 2, \ldots, n;\ k = 1, 2, 3, 4$

$\Sigma_{ip}\ y_{ijp} = b_j$ for $j = 1, 2, \ldots, n$

$\Sigma_i\ z_{ijl} = c_{jl}$ for $j = 1, 2, \ldots, n;\ l = 1, 2, \ldots, g$

$\Sigma_j\ f_{ijp} \cdot y_{ijp} \leqq F_{ip}$ for $p = 1, 2, \ldots, m;\ i = 1, 2, 3, 4$

$\Sigma_j\ x_{ijk} \geqq s_{ik}$ for $i,k = 1, 2, 3, 4$

$x_{ijk}, y_{ijp}, z_{ijl} \geqq 0$

Additional relations determining the levels of y_{ijp} must be specified to represent the particular types of management practiced.

Notation:

x_{ijk} - volume harvested of assortment k, in period i, from area j

y_{ijp} - timber logged in m^3 with method p, during period i, in area j

z_{ijl} - silvicultural activities l carried out during period i, in area j, expressed in various units (ha, km, etc.)

a_{jk} - annual volume requirement in m^3 for assortment k from area j

b_j - annual target volume logged--by all methods-in area j

c_{jl} - annual target for silvicultural activity l on area j

i - quarter of the year, $i = 1, 2, 3, 4$

j - gravitational areas, $j = 1, 2, 3, \ldots, n$

p - kind of logging method, $p = 1, 2, 3, \ldots, m$

k - combination of the type of harvest and species group (e.g., final-coniferous: $k = 1$, intermediate-coniferous: $k = 2$; etc.), $k = 1, 2, 3, 4$.

l - kind of silvicultural activities, $l = 1, 2, . . ., g$

F_{ip} - available inputs for logging with method p in period i

f_{ijp} - quantity of input per m^3 required to log with method p in period i and area j

s_{ik} - total volume required by the sale plan in quarter i for the kth combination of type of harvest and species group

g_{ijk}, r_{ijp}, u_{ijl} - coefficients of objective function, giving the costs for technical unit according to the kind of silvicultural activity

Because the planning problem has been specified as a linear program, it is relatively easy to solve it with a computer, in spite of the large dimension of the linear program required under real conditions.

The planning problem is specified as a deterministic model in spite of the stochastic characteristics of forest production. This shortcoming of the model may be compensated for by solving the model for various values of the coefficients of the LP matrix or of the objective function.

A mathematical model requires information which can be divided into technical and economic parameters. The technical parameters include the knowledge of possible technological alternatives for work procedures, available resources or capacities and scheduled means of production. Economic parameters represent data on costs which vary with the location of the activity and its technical characteristics.

To obtain all the necessary information for the model usually requires changes in the information system. Our present experience indicates that the information system must be developed concurrently with the mathematical model.

CONCLUSION

The use of this mathematical model contributes the following positive elements to planning:

It balances the requirements of production and technical means and workers available

It balances the sources of wood, with the wood assortment requirements of the national economy

It coordinates the distributing of production over time with the requirements of national economy

It realizes the plan specification at minimum costs

The results which we have obtained establish the possibility of planning and controlling production in forestry. These results also indicate that by using operations research models, planning and control can be made more effective.

Large-Scale Budget Applications of Mathematical Programming in the Forest Service

Malcolm Kirby

Abstract: Mathematical programming applications in the Forest Service, U.S. Department of Agriculture, are growing. They are being used for widely varying problems: budgeting, land use planning, timber transport, road maintenance and timber harvest planning. Large-scale applications are being made in budgeting. The model that is described can be used by developing economies.

INTRODUCTION

Two modern techniques of optimization that can be applied to complex resource problems are ADVENT (Kirby and others 1976) and the Eldorado model (Bell and Kirby 1971; Kirby 1971a, 1971b). They are so closely related that it is convenient to refer to both as "the model." The basic premise is that land management requires more than one input (men, money) and usually results in more than one output. The model uses linear programming to handle tradeoff relationships and to evaluate the effects of imposing or relaxing levels of inputs, outputs, or both. The management objectives for the model were to prepare a budget request relating outputs to inputs; and once funds are allocated, to select projects that will either meet a set of output goals at minimum cost or will maximize a selected output (Bell and Kirby 1971).

Traditionally, work planning in the National Forests was based on specific resources functions: timber, range, recreation, watershed, etc. Each function used its funds to maximize specific outputs. Through so-called "multiple use" coordination, the effects of one function on another's outputs were considered but seldom explicitly evaluated. But the model does this explicitly, and this is what makes some managers uncomfortable with it. It requires that goals be stated in specific terms: animal unit months (AUM) of forage rather than acres reseeded; cubic feet of timber produced rather than acres planted; specific effects on all outputs as a result of building a road rather than miles of road built.

A list of outputs from a typical National Forest include timber, recreation, water, wildlife grazing, and livestock grazing. In addition, there are miles of spectacular scenery, numerous lakes, miles of fishing streams, wilderness, power houses, summer homes, ski resorts, irrigation canals, roads, trails, dams, pipe lines, organization camps, and other sundry special uses such as a temporary high altitude training camp for the Olympics.

National Forest planners are faced with three limitations: limited land, limited funds, and pressures for fulfilling the needs of an ever-increasing population. The planning problems are very complex. Goals include meeting the demands for outputs and maintaining the local economies, maintaining a trained work force, and maintaining the productivity of the land.

Work done on National Forest lands requires multiple inputs--land and money (let money here represent tools, equipment, supplies and manpower). These inputs result in multiple outputs--forage, water (both quantity and quality), soil stability or erosion, camping, picnicking, fishing, hunting, timber growth, and timber cut. There are also more nebulous outputs (or effects) such as aesthetics, fire risk, air quality, and so on. These effects vary depending on the productive capability of the land, the primary purpose of the work being done, the methods used, and the spatial position of the land being treated.

The model is used for preparing proposals either for one or more future fiscal years or for the fiscal year that is about to begin. It is now being used for both budgeting and long-range planning at the local and national levels. We have also used ADVENT for trade-off analyses in land use planning, where long range timber yield considerations are not important.

The model is designed to generate a large number of feasible alternative programs. The design criteria are that the model be multiple-output oriented, able to generate alternative programs that are feasible, able to report the future implications of various alternatives, and able to generate optimal alternative programs on the basis of output-oriented criteria.

PROBLEMS IN IMPLEMENTATION

Some of the problems in implementing such a model are these:

> People: To begin with, when you say, "Here is a better way to prepare a budget request," you have insulted those who have been following another system for a number of years. They have two reactions: "What's wrong with the way we've been doing it?" and "Show me."
>
> Data: The amount of data needed for a complex mathematical model is formidable. Everything must be reduced to numbers.
>
> Goals: They must be specific and quantifiable; narrative statements cannot be used. The manager may have to use hunches in interpreting the results, but the model cannot.

The people problem is very real. There is a generation gap between the top managers and a fast-growing group of mathematicians and economists. Managers are not used to thinking in terms of abstractions. It behooves both the teachers and the practitioners to take the time and effort to strip away the mystery, interpret the jargon into terms that can be understood, forget the theory, and show by actual examples what is meant. If we seem to labor this point, it is because we fear that if young people, exposed to new methods and techniques, do not recognize the problem, they will be frustrated when their ideas are not received with enthusiasm.

The land manager can have faith that these models work with great mathematical accuracy. However, he should scrutinize the figures, make sure they are correct, and test the final answers on the basis of reasonableness.

What about data? After all these years of research, we do not have all the information needed. For example, we have fairly reliable information as to the effect of a specified thinning regime on the volume growth of timber over time, when we know the site class. What we do not always know is the effect of the thinning on the forage output for domestic or wild grazing animals, or the effects on water runoff, or the tons of fuel per acre resulting from one thinning operation, or whether leaving the slash on the ground is more beneficial for protecting the site than it is detrimental as a fire hazard. During the development of the Eldorado model, we reviewed nearly a thousand research papers and found less than 20 that were helpful in assessing effects on more than one output.

What about goals? Traditionally managers set goals in rather general terms--for example: meet the allowable cut, thin 1,000 acres, eradicate 500 acres of sagebrush, build 5 miles of fence. The model requires goals that are related directly to outputs such as cubic feet of timber growth, AUM's of forage produced, or tons of soil per acre that would remain in place if a protective fence were built. Specific goals such as these are very difficult to set. The output goals that we considered included the following:

Timber Cut
Timber Growth
Timber Regeneration
Livestock Grazing
Wildlife Grazing
Water Runoff
Water Quality
Soil Stability
Recreation Environment
Recreation Visitor Days
Fire Hazard Reduction
Fire Accessibility

The manager who is comparing two alternative forest-wide programs can scan the computer printouts and decide if one program is better or worse than the other and if the increase in output is worth the decrease in some other output. Inasmuch as output information is limited at this time, he cannot make his decision on the basis of actual physical outputs alone.

BASIS FOR DECISIONS

Some managers are uncomfortable with the model because there is no single criterion that indicates the "best" choice. To overcome this drawback some economists suggest converting everything to dollars and selecting projects based on benefit/cost ratio, or present worth, or internal rate of return, etc. This approach would be ideal except for four problems:

Difficulty of measuring all of the desired outputs for each project
Difficulty of assigning dollar values to all of the outputs
The specific statement in the "Multiple Use Sustained Yield Act" that the management of National Forest lands is not to be based upon the highest dollar return
The non-uniqueness of dollar values which give the same answer

There are many kinds of values--for example, market value, consumer value (a willingness to pay), producer value (the cost to produce), increasing gross national product, monopoly revenue value, and expenditure value. Whaley (1968) defines six different value methods. He points out that the value system must be appropriate for the model, must use the same method for achieving values for all outputs and must allow the values to be empirically quantifiable. The point is that since so many different kinds of values exist, the absence of a value system means the choice of method for valuing outputs can be rather arbitrary. To date, such a system has not been adopted for the Forest Service.

What then is the basis for decisions? Again, Whaley (1968) lists four measures of program effectiveness which may be used in public resource management: meet established production goals at least cost, establish the budget level and maximize some outputs, claim that no rational solution exists (we don't make this claim!), and maximize economic development. The Annual Budget Model and ADVENT were designed for using any of these measures. Therefore, when values for outputs are developed, by any value system, they can be easily employed in the model. Regardless of the manager's value systems, he still needs alternative programs from which to choose, and the model makes it easy to generate alternative programs. The models simply process information, bringing into focus the sociological, economic, and organizational consequences of alternative decisions. The final selection rests with the land managers and Congress, who must weight the socio-economic and political impact of their decisions.

The linear programming part of the model can carry out the following steps:

(1) determine whether or not the problem can be solved
(2) if it is solvable, give an optimum solution
(3) allow constraints of outputs, money, manpower, activity types
(4) maximize an output for a given budget or, provide a specified output level at minimum cost
(5) provide a budget which includes all the costs of the various projects

ADVENT also has a goal programming option to minimize the deviations from a set of goals or "targets".

The model has reporting capabilities to transform the original data into a series of abbreviated reports or complete reports as desired by the manager. Information available for each solution includes manpower needs by skills, by sub-units; money needed; list of projects selected; and list of total outputs.

One of the drawbacks, in the opinion of some managers, is that using it requires that more work be planned than there will be money to do. This represents extra effort which in times of tight budgets seems useless Extra projects must be provided or there is no choice. Another drawback is that the time frame of 1 year is too short. This is admittedly a disadvantage, but budgeting, particularly fund allocation, is a year-to-year process. As already pointed out, there is a shortage of estimates of multiple outputs and "relative effects" are an unfamiliar substitute. The model requires that goals be set in quantitative terms. This has proved difficult at first.

Positive advantages of the model are that it considers the joint effect of inputs on outputs; it gives the manager a tool to explore a series of alternatives; and it focuses attention on specific measurable goals rather than broad overall objectives.

NUMERICAL EXAMPLE

To illustrate how the model works, let us consider a small hypothetical numerical example of eight projects, as follows:

Item	1	2	3	4	5	6	7	8
Land management and administration:								
Expenditures (million dollars)	2	3	3	2	4	2	4	4
Manpower (man-years)	100	100	100	50	300	100	100	100
Road construction and maintenance:								
Expenditures (million dollars)	7	6	3	1	1	3	2	3
Manpower (man-years)	200	100	100	100	100	200	100	100
Timber, for the next decade:								
Average annual cut (1000 bd. ft.)	8	9	8	7	5	4	5	2
Average annual net growth (1000 bd. ft.)	9	9	8	7	6	5	5	3
Benefits and costs:								
Total value of output (million dollars)	28	27	15	6	9	8	8	7
Total expenditures (million dollars)	9	9	6	3	5	5	6	7
Administrative priority rating:	1	1	2	3	5	4	5	5

Suppose we wish to select a project mix that meets the following specifications:

(a) Include project 1 because it is already under contract
(b) Include all projects with priorities 1 and 2
(c) If project 7 is included, project 8 must also be included, and vice versa
(d) Do not permit both projects 5 and 6: one or the other, but not both (they are close substitutes)
(e) Achieve a minimum level of timber growth of 43
(f) If there is a tie, then choose the combination of projects that minimizes total land management costs

(Note that in addition to constraining the level of individual inputs and outputs, or their combinations, the user can control individual projects or their combinations).

The solution is as follows:

Project No.:	1	2	3	4	5	6	7	8
Percentage:	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes

The solution is presented below in the format of one of the 22 reports which can be prepared with ADVENT. Both the input data and the information contained in the LP solution can be displayed in these reports. The user can also employ ADVENT in a pure simulation mode by selecting a set of projects on the basis of experience and intuition, and call for a report detailing the corresponding costs, revenues, outputs, activities, manpower requirements, etc.

ADVENT report corresponding to the LP solution of the numerical example

```
*** PROJECTS SELECTED ***


AGGREGATE WORK/ACTIVITY DESCRIPTION                AMOUNT

. . . . . . . . . . . . . . . . .                  ......

PLANTING & SITE PREPARATION                             600  ACRES
SLASH REDUCTION                                       1,000  ACRES
PRECOMMERCIAL THINNING                                  400  ACRES
TIMBER SALES PREPARATION                              2,000  ACRES
ROAD MAINTENANCE                                        300  MILES
ROAD CONSTRUCTION                                        75  MILES



AGGREGATE OUTPUT DESCRIPTION                       AMOUNT

. . . . . . . . . . . . . .                        ......

DISPERSED RECREATION USE                             20,000  VISITS
TIMBER HARVESTED                                     80,000  MBF
TIMBER SOLD                                          85,000  MBF
WILDLIFE HABITAT IMPROVEMENT                          5,000  ACRES
VALUE OF TIMBER HARVESTED                        47,000,000  $



AGGREGATE COST DESCRIPTION                         AMOUNT

. . . . . . . . . . . . .                          ......

TOTAL EXPENDITURES                               50,000,000  $
TOTAL ROAD CONSTRUCTION & MAINTENANCE            25,000,000  $
TOTAL LAND MANAGEMENT & ADMINISTRATION           25,000,000  $
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MATHEMATICAL FORMULATION

For the reader interested in the mathematical formulation we present a simplified version of the linear programming problem.

$$\text{maximize } \Sigma_j \quad d_j x_j \qquad \text{subject to:}$$

$$\Sigma_j \, a_{ij} \, x_j \geqq f_i, \qquad i = 1, 2, \ldots I,$$

$$\Sigma_j \, c_{kj} \, x_j \leqq b_k, \qquad k = 1, 2, \ldots K,$$

where:

x_j = 1 if the project is selected and zero otherwise

a_{ij} = amount of the i^{th} output per unit of x_j

c_{kj} = amount of the k^{th} input per unit of x_j

f_i = constraint on the total amount of the i^{th} output

b_k = constraint on the total amount of the k^{th} input

I is the set of output categories

K is the set of input categories

and where d_j may be chosen as

a_{ij} if the i^{th} output (e.g. timber growth) is to be maximized

or

$-c_{kj}$ if the k^{th} input is to be minimized

or

$-\Sigma_{k \varepsilon K^*} c_{kj}$ where K^* is a subset of commensurable inputs such as costs or manpower

The term d_j may also be specified as the discounted or undiscounted total net revenue.

Note that the problem is formulated as an integer program, but it is solved by means of a linear programming routine. The reason is that the solution generally turns out to be an excellent approximation to the integer solution, and the computer time is very short compared to the time required to solve the corresponding integer program. It is this feature that makes ADVENT a practical tool for widespread use. A discussion of why these approximations work as they do may be found in McConnen and others (1966).

CONCLUSION

ADVENT can be used by developing economies for both budgeting and long range planning. It has been tested in many different uses, over more than 4 years, by more than 50 organizations. The model's flexible design permits other planning applications such as road maintenance, capital investment analysis, project selection and other trade-off analyses. It is designed for use by relatively unskilled users of computers. The cost of a typical computer run, for 400 projects, is about $50.

REFERENCES

Bell, F., and M. Kirby. 1971. An example of optimization techniques in land Management: The Eldorado model. Forest Service, U.S. Dep. Agric., Berkeley, Calif.

Kirby, M.W. 1971a. An overview of program budgeting on a National Forest. Forest Service, U.S. Dep. Agric., Berkeley, Calif.

Kirby, M.W. 1971b. The methodology of program budgeting on a National Forest: The Eldorado experience. Forest Service, U.S. Dep. Agric., Berkeley, Calif.

Kirby, M.W. 1974. A model for allocating road maintenance funds. [Unpublished paper on file, Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.]

Kirby, M.W., D. Wegner, L. Visser. 1976. ADVENT: A user's guide", 2nd Edition, Forest Service, U.S. Dep. Agric., Berkeley, Calif.

McConnen, R., M. Kirby, D. Navon. 1966. A planning programming budgeting system for National Forest Administration. [Unpublished report on file, Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.]

Whaley, R.S. 1968. Multiple use decision-making: where do we go from here? [Unpublished report on file, Rocky Mountain Forest and Range Exp. Stn., Fort Collins, Colo.] .

Forest Management Planning for Timber Production: A Sequential Approach

Krishna P. Rustagi

Abstract: Explicit forest management planning for timber production beyond the first few years at any time necessitates use of information which can best be described as suspect. The two-step approach outlined here concentrates on the planning strategy over the next few years without losing sight of the long-run productivity. Frequent updating of the long-range and short-range plan makes it possible to keep a dynamic posture. Instead of one single objective of maximization of discounted present net worth, there are two objectives. The short-run objective implicitly maximizes the volume or the discounted present net worth of timber harvested during the first rotation, subject to equal area constraint; the long-run objective explicitly maximizes the rate of return to the land either as timber volume (MAI) or annualized land rent. The reduced size of the two problems makes this approach extremely practical.

INTRODUCTION

Timber management planning essentially involves decisions on two basic issues: temporal and spatial scheduling of harvest during a planning period and the reforestation strategy that is to follow each harvest. The former provides the amount of timber and income flow during the planning period. The latter does much more. It indicates the flow of timber and income one rotation in the future, the needed reforestation investment during the planning period, and the rate of return to the land under the proposed alternative(s). These short and long-run flows are shaped by the management objectives, spatial distribution of growing stock, and restrictions, if any, on the level of harvest and/or reforestation activities.

Combining harvest scheduling with reforestation planning in one model puts heavy demand on the information needs. Not only are yield, stumpage price, and reforestation and other costs needed for each stand, but the same information must be projected for several decades and perhaps centuries. The net result is an excessively large model and less than reliable input.

If the forest schedule can be separated from the reforestation plan, the resulting two models would be relatively small and need far less data. The net result: operatively practical models with better control on the quality of input at far less effort. The two-stage sequential approach is an attempt in this direction.

UNCONSTRAINED OPTIMIZATION

The economic management objective is usually taken as a maximization of discounted present net worth over a number of rotations. If there are no restrictions on the level of activities, the same result could be accomplished by setting up a performance standard for each stand and evaluating its performance against this standard. Stands which are performing poorly should be harvested and reforested with the alternative(s) which maximize soil expectation value (SEV). Mathematically, a stand should be harvested if:

$$MR - iR < i(SEV)$$

Where

MR = marginal value growth in a stand if its harvest is postponed for one year

R = current value upon harvest

i = interest rate

SEV = maximum soil expectation value possible on that site under the given reforestation alternatives.

Although this criterion for harvest scheduling looks innocently simple, it is extremely difficult to apply in practice. The value growth MR is affected by volume growth, timber quality improvement (better diameter, height and tree form), and appreciation (or depreciation) in stumpage prices due to inflation and cycling in economy. In addition, both R and MR are influenced by the price elasticity of stumpage demand.

Adoption of this criterion would maximize the long-run discounted present net worth for the entire forest without actual use of a sophisticated model. It may be pointed out, however, that if the forest is unbalanced to start with, the uneven or interrupted yearly (or periodic) flow of timber will be perpetuated.

CONSTRAINED OPTIMIZATION

In public and industrial ownerships, certain restrictions are imposed on the level of activities in order to ensure long-run sustained flow of timber. These restrictions usually result in regulation of harvest by equal volume or area over time. Though restrictions of any kind would reduce the total discounted net present worth, volume regulation tends to be more restrictive and gives rise to the spectacular but controversial allowable cut effect

(Schweitzer and others 1972). Further, it is impossible to obtain strict even flow due to a variety of reasons, including unbalanced initial forest structure, impreciseness in the estimation of growth and yield over time, changes in utilization standards and technology, and changes in the management intensity.

Area regulation would also produce fluctuating harvest during the conversion period (first rotation) but ensure more predictable and sustainable long-term harvest. Other advantages of area regulation include predictability and stability of reforestation investment and overall management-related activities.

Linear programming models are often used for constrained optimization (Navon 1971, Clutter and others 1968). Nautiyal and Pearse (1967) also presented a theoretical model for maximizing discounted present net worth subject to area regulation. Though theoretically correct, these models are not very practical because of huge data needs and immense problem size. Past experience has indicated that precise estimation of yield and growth, operations costs, stumpage prices and interest rates are not possible beyond a few years and yet these models require this information for at least one rotation and often for more than a century!

In view of this, some real questions may be raised. How sophisticated should a model be, when the data cannot be obtained with any degree of reliability? How intensively should such data be used by the model? How far into the future should the planning horizon extend? Obviously, the sophistication of the model should match the sophistication of the data input; if the data needs can be reduced both with respect to time and space, it may be possible to direct more attention to the data collection effort, thus improving the overall planning.

THE SEQUENTIAL APPROACH

If the management planning problem is partitioned into two components, these would be (a) harvest and thinning scheduling and (b) reforestation planning. In the sequential approach these two components are handled one at a time.

Harvest scheduling is a disinvestment process, and focuses primarily on timber and cash flow during the planning period. The entire existing volume in a forest, together with its growth, is to be harvested before the first planned reforestations mature. Any harvest scheduling strategy may be used between the performance standard approach at the one extreme and equal annual (or periodic) volume at the other extreme. Because of its focus on output and income in the near future, harvest scheduling may be termed short-range planning.

Reforestation implies deliberate investment of capital with land. The focus here is on productivity and profitability of investment which will be realized one rotation in the future. The level of investment in reforestation coupled with the productive potential of the forest lands essentially determine future productivity and profitability. Because of its long-range (beyond first rotation) implications, reforestation planning may be termed long-range planning.

The objectives and data needs for the two components are entirely different. In harvest scheduling, information is needed by individual stands which may be characterized by species, site, age, stocking, and accessibility. Both quantitative and qualitative data on yield and the expected stumpage prices are needed for each stand and each year of the conversion period. It will be shown, however, that the yield and stumpage price information may be needed only for a subset of all stands and only for a fraction of the conversion period.

The data needs for reforestation planning involve only operations after harvest. These include reforestation cost, expected total yield and stumpage prices for likely species, management regimes and rotation lengths. Only classification of the forest area needed here is by site, accessibility, and perhaps conversion costs.

Two assumptions are the basis for this sequential approach: (1) the future rotation determination is not influenced by the existing growing stock, and (2) the proposed reforestation planning must be optimal independently of the harvest strategy used. These two assumptions enable us to partition one immense single constrained optimization problem into two relatively very small optimization problems.

Rotation of the future crop--determined by the reforestation plan--indicates the time span in which the existing growing stock and growth thereupon has to be harvested. Therefore, if continuous timber flow is required, the harvest scheduling should be preceded by the long-range plan. In the sequential approach, the long-range plan is developed first. The long-range plan is best summarized as follows:

Long-Range Plan (Reforestation)

Objective: Maximization of long-run timber output or rate of return to the land

Constraints:
I. Reforestation of equal annual (or periodic) areas by site
II. Equal annual (or periodic) reforestation budget

Input:
I. Area distribution by site, accessibility, etc.
II. For each site and species, method of regeneration, initial stocking level, management regime, and rotation:
  - Total reforestation and subsequent management costs
  - Expected product output at rotation age
  - Expected annual rate of return to the land

Output:
I. Area to be reforested annually
II. The reforestation schedule together with rotation lengths by site
III. The long run annual total timber output
IV. The long run annual total income from the use of forest land

The long-range planning problem could be handled by linear programming (LP) if the management objective is either long-run timber yield maximization or the maximization of rate of return to the land. If a combination of both is desired, the problem could be handled by goal programming (Rustagi 1976). As the problem size would be small--only a few hundred variables at most--there would be scope for refining site classification, and including a large number of regeneration methods, and management regimes, and several rotations. The small size of the problem would also enable in-depth sensitivity analysis.

The long-range plan gives an annual reforestation program which will maximize long-run income from the use of forest land subject to area and reforestation budget constraint. If there is no constraint on reforestation budget, the plan would indicate annual budget needs to implement the reforestation program. This program may be implemented as long as the input or the constraints do not change. If any change does take place, the problem can be easily reformulated and solved.

Once the areas to be reforested by site and accessibility classes have been determined by the long-range plan, their geographic location must be determined. In the second stage of the sequential planning, a harvest schedule is developed which tells where, when, and how much to harvest in different years of the conversion period. This harvest scheduling problem may be summarized as follows:

Short-Range Plan (Harvest Schedule)

Objective: Maximization of discounted harvest income from existing stands or maximization of total timber yield during the conversion period

Constraint: Area to be harvested in each year by site and accessibility class as given by the long-range plan

Input: Estimate of yield and expected stumpage prices for each stand and for each year of the conversion period

Output: For each year of the conversion period

I. Geographical location of stands to be harvested
II. Expected harvest volume
III. Expected income from harvest

Though theoretically this harvest schedule should be prepared for the entire conversion period, it is not really necessary to do so. Those stands which are putting on the least volume or value growth in each site will be the first to be scheduled for harvest. Likely candidates for this category include stands past maturity, grossly understocked stands, or stands currently under less economic species. Immature stands which are growing vigorously are unlikely to be taken up for harvest for some time. Thus, if a harvest schedule is prepared for 10 years at a time using only a proportionate area comprising the least vigorously growing stands, and the plan is implemented for the first 5 years and revised, the planning outcome will be as optimal as if the schedule is prepared for the entire conversion period.

There are two significant advantages in harvest scheduling for a shorter period. First, only a fraction of the total forest area need be considered by the harvest schedule: thus, more precise estimates of volume and value are possible for a given amount of effort. Second, as the harvest schedule is to be for only 10 years (maybe less), relatively reliable estimates of stumpage values and harvest costs are possible. In short, the amount of information to be collected may be as small as 10 percent of what would be needed to prepare a harvest schedule for the entire conversion period.

The harvest scheduling problem may be handled by linear programming. However, with an area constraint, different management objectives or different scheduling strategies, such as oldest stand first, should not produce significantly different impacts on the objective function value. An arbitrarily determined harvest schedule based on roading condition and proximity of stands to be harvested--which may not be built into an LP model--may outperform the schedule drawn by using LP.

DISCUSSION

Suppose one million hectares of forest land is to be managed for sustained production with the long-run objective of maximization of income to the land. Also suppose that there is a constraint on the reforestation of income to the land. Also suppose that there is a constraint on the reforestation budget. Further, suppose that based on productivity, accessibility, administrative considerations, and conversion possibilities, this forest land can be divided into 10 site classes, and for each site class, 5 reforestation alternatives are available, with information on reforestation cost, rotation lengths, total timber output, and income from harvest at rotation age.

The long-range problem, if the sequential approach is used, will have only 50 decision variables, 10 area constraints and one budget constraint. The solution will include the number of hectares to be harvested and reforested and the rotation to be adopted in each site class. Also, total long-run timber output and income from the use of forest land can be computed.

Suppose that this million hectares can be divided into 10,000 homogeneous stands. If the short-range plan is to be prepared for 10 years, with an average rotation length of 50 years, yield and stumpage information will be needed for approximately 2,000 stands covering 200,000 hectares. If formulated as an LP problem, it will have about 20,000 decision variables and 2,050 constraints. The problem size may be substantially smaller if the rotation is longer than 50 years or the planning period is shorter than 10 years. For example, a 5-year planning period may result in only 5,000 decision variables and 1,025 constraints.

If, however, the two components are merged into one model such as Timber-RAM (Navon 1971), and a plan is prepared for the next 50 years with the same degree of spatial and temporal resolution, the number of decision variables will increase to one million with number of constraints in excess of 10,000. Whereas this large problem size will force aggregation, further resolution is possible under the sequential approach.

The advantages of the sequential approach to timber management planning may be summarized as follows:

1. The size of both the long and short-range problems are small. This makes it possible to examine a much larger number of investment alternatives and exercise better control on the quality of input.

2. The long-range plan provides long-run predictions of timber output without actually developing a management plan for a rotation or longer period.

3. The investment analysis of planned reforestations is very explicit and separate from current harvest income.

4. As the regulation of harvest is not by volume, allowable cut effect (Schweitzer and others 1972) cannot be used for distorting investment analysis.

5. Because of small problem sizes, as frequent as annual updating of both long-range and short-range plans is practical.

It may be argued that the long-range plan described here also uses estimates of costs and stumpage process up to the end of a rotation. Unfortunately, there is no way to avoid use of these numbers if the reforestation investments are to be evaluated according to some economic criterion. These numbers will not be needed, however, if a biological criterion is used in establishing maturity. If it is assumed that the stumpage price will maintain the historical rising trend in the foreseeable future, and that thinning and fertilization will be used increasingly, the financial rotation using Faustmann's formula may not be significantly different from the rotation of maximum volume production, which can be predicted with greater accuracy and is unaffected by economic factors such as costs, stumpage prices, and interest rates.

Though the long-range plan has equal area constraint, this may be relaxed to take advantage of the timber market so long as these variations even out in the long run. This flexibility of scaling harvest up and down is available only so long as some kind of long-run sustained harvest is followed.

Thinnings were excluded purposely from harvest scheduling. Though commercial thinning is income producing, it is essentially a silvicultural operation carried out to increase the value growth of the residual stand and to prevent mortality loss. When and where to thin may be best decided after a harvest schedule has been prepared. Coordination of thinnings with harvest cut in nearby areas may provide better return than may be possible otherwise.

An application of the sequential two-step approach outlined here has been presented by Rustagi (1976) where the long-range reforestation planning has been handled by goal programming and the short-range harvest scheduling by linear programming. This application reveals that with equal area constraint, total discounted present value of harvest during a planning period is not significantly different whether the objective is biologic or economic. The actual harvest schedule, however, may vary with the short-run objective.

LITERATURE CITED

Nautiyal, J.C., and P.H. Pearse. 1967. Optimizing the conversion to sustained yield - a programming solution. Forest Sci. 13(2):131-139.

Navon, Daniel I. 1971. Timber RAM....a long-range planning method for commercial timber lands under multiple-use management. USDA Forest Serv. Res. Paper PSW-70, 22 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Rustagi, Krishna P. 1976. Forest management planning for timber production: a goal programming approach. Yale Univ. Sch. For. Environ. Stud. Bull. 89, 80 p.

Schweitzer, D.L., R.W. Sassaman, and C.H. Schallau. 1972. Allowable cut effect - some physical and economic implications. J. For. 70(7):415-418.

University of Georgia, School of Forest Resources. 1968. Max-million: a computerized forest management system. Athens, Ga. 61 p.

A Two-Phase Method for Timber Supply Analysis

Stephen Smith

Abstract: There is an increasing need to clarify the long-term wood supply implications of current harvesting rates. To assess the wood supply and to set timber production objectives, different linear programming techniques are applied to the short and long term. The transportation method is applied to the short term and the B. C. Forest Service computer-assisted resource planning method is applied to the long term.

INTRODUCTION

Of all the decisions facing forest policymakers, probably the most critical, because of its economic importance, is the rate at which timber is to be made available for harvesting. The timber-producing base is diminishing through increased recognition of an array of legitimate non-timber users, through environmental protection measures, and through changes in the economics of logging. The nature of the productive forests is changing from unmanaged large old-growth to young-growth forests whose products will be smaller and in different proportions by species. In this changing world the British Columbia Forest Service must maintain a continuing wood supply to support a healthy competitive forest industry and ensure the productive integration of land uses. All these factors generate an increasing need to clarify the long-term wood supply implications of present timber harvesting rates.

In 1976 the Royal Commission on Forest Resources (Pearse 1976) recommended changes in the current methods of timber yield regulation. In particular it recommended that yield controls should (1) apply to Timber Supply Areas (TSA's) serving manufacturing areas and communities, (2) recognize log supply patterns and transportation facilities within the timber supply area, (3) embody reasonable expectations about future trends in forest growth and values, and (4) recognize the uncertainty surrounding long-term forecasts. This paper describes a small part of the response by the British Columbia Forest Service to these recommendations.

TIMBER SUPPLY AREAS

Within the regions of the Province, timber supply areas can be identified which serve manufacturing areas and communities. The supply areas have largely evolved from establishment of forest industry and the development of associated communities. Insofar as public policy is to be directed toward supporting the income and employment base of forest-dependent communities, yield controls must be designed to apply to the relevant timber supply areas. There should be some flexibility in setting short-term harvesting rates, together with a mechanism for clearly showing their long-term implications for the future wood supply.

TWO-PHASE METHOD

To meet the described requirements for revised yield controls, the approach has been to separate the relatively short term (the next 20 years) from the very long term (about two rotations). In defining timber production objectives over the 20-year horizon, the Forest Service must ensure that the short-term rate of cut will not result in an unacceptable decrease in the future wood supply. Accordingly a practical, conceptually simple process consisting of two phases has been developed, from which timber supply area wood production goals can be derived.

Phase 1 (Short Term)

Develop and describe 20-year production goals in the form of a simple wood flow plan. The plan describes a feasible, efficient movement of wood from the different localities within the timber supply area to the different broad industrial sectors. In practice this 20-year "look ahead" would be used to set 10-year objectives. The 10-year production objectives are to be reviewed every 5 years.

Phase 2 (Long Term)

Determine the projected timber production curve over one or two rotations for the entire timber supply area, setting the overall cutting rate for the first two decades equal to that developed in phase 1.

If the results of phase 1 cause the long-term rate of cut to drop below the 90% of the long-run sustainable yield, then phase 1 must be modified until it is in harmony with the long term goals.

FORMULATION OF THE SHORT-TERM ANALYSIS

The supply area can be described as a network in which there are localities (supply points) supplying industrial sectors (demand points). The 20-year horizon can be divided into four 5-year periods. Each supply point has an inventory of accessible, usable timber; each demand point has a minimum demand to be satisfied and a physical capacity which cannot be exceeded. The objective is to select, for the duration of the horizon, a routing plan which satisfies all the demands, does not exceed the supplies and physical plant capacities, and attempts to maximize the value of the routing plan.

One formulation of the problem is given below:

Maximize $\Sigma_{ijk}\ r_{ijk}\ x_{ijk}$

Subject to the demand constraints:

$-\Sigma_{jk} x_{ijk} \leq D_i$	minimum total sector demands over the 20 year horizon	(1)
$-\Sigma_{jk} x_{ijk} \geq M_i$	maximum total sector demands over the 20 year horizon	(2)
$\Sigma_j - a_{ijks}\ x_{ijk} \geq SD_{iks}$	maximum sector demand by species and time period	(3)

where $-SD_{iks} = -g_{iks}P_{ik}$

$-\Sigma_j\ x_{ijk} \leq PD_{ik}$	minimum total demand by sector i in time period k	(4)

and subject to the supply constraints:

$\Sigma_{ijk}\ x_{ijk} \leq T$	total wood supply	(5)
$\Sigma_i\Sigma_k\ x_{ijk} \leq S_j$	total wood supply for each management unit	(6)
$\Sigma_i\ x_{ijk} \leq MS_{jk}$	wood supply for each management unit in each time period	(7)
$\Sigma_k\ x_{ijk} \leq SS_{ij}$	total supply available to sector i from management unit j over the 20 year horizon	(8)

x_{ijk} = volume of wood allocated to sector i from management unit j in time period k

r_{ijk} = value of a unit of wood allocated to sector i from management time unit j in time period k

D_i = total minimum demand for sector i over the 20 year horizon

M_i = total maximum demand for sector i over the 20 year horizon

P_{ik} = maximum demand for sector i in time period k

a_{ijks} = proportion of species s in a unit of wood from management unit j which can be used by sector i in time period k

SD_{iks} = maximum demand by sector i for species s in time period k

g_{iks} = the average proportion of species s used by sector i in time period k

PD_{ik} = minimum total demand by sector i in time period k

T = total wood supply in the supply area available for cutting in the next 20 years

S_j = total wood supply in the jth management unit available for cutting in the next 20 years

MS_{jk} = total wood supply from management unit j in time period k

SS_{ij} = total supply available to sector i from management unit j over the 20 year horizon

$i = 1,5 \quad j = 1,10 \quad k = 1,4 \quad s = 1,6$

LONG-TERM ANALYSIS

Obviously it is not sufficient to allocate existing mature timber inventories from the management units within the supply area, without looking at the long-term consequences for the supply area as a whole. Use of a subset of the Computer Assisted Resource Planning System (Williams and others 1975) allows calculation of a long-term production curve for the entire timber supply area, constrained for the first two decades to the harvest level set in the short-term calculation. In this calculation the harvest scheduling formulation is that produced by Timber-RAM (Navon 1971).

APPLICATION OF THE METHOD

After assessing present and projected industrial demands and the net timber supply, a simple question-and-answer sequence can be followed to arrive at a set of timber production goals. Those questions, in the order that they are addressed in the process, are:

Can the present cutting rates be maintained over the next twenty years?

What effect will maintenance of the present cutting rate have on long-term timber supply?

What are the projected increased industrial demands over the next twenty years and can cutting rates be raised to meet them?

If increased demands can be met over the next twenty years, what will be the effect on the long term supply?

The method also has the following capabilities:

Likely periods of scarcity for a particular industrial sector can be highlighted.

Areas that have to be developed by a certain time to meet wood supply needs can be pinpointed.

The effects of changing sector demands on the wood supply picture can be predicted.

The effects of changing the log supply pattern on the wood supply picture can be predicted.

A starting point is given for long-range strategies to ameliorate impending wood supply problems if they are indicated.

RELATING TO NONTIMBER RESOURCE USES

An initial wood supply analysis provides valuable input to determining overall resource use policy. With this information "out on the table" other resource managers can participate effectively in the development of alternatives for a timber supply area and, later on, for a complete region.

Once alternatives are developed which express the needs of other resources, one can be chosen by the decisionmakers, or additional alternatives can be prepared prior to the decision.

RESULTS OF THE PROCESS

Tables and graphs are generated showing planned rates of harvest for the timber supply area in each of the next four 5-year periods. Planning harvest rates are broken down by management unit and industrial sector.

For the long term, graphs and tables are generated allowing an assessment of the long-term wood supply which will result from implementing the 20-year harvesting plan.

These results enable the Forest Service to set timber production objectives and are a starting basis for the development of associated reforestation and silvicultural goals.

The method outlined in this paper is part of the Forest Service planning system (British Columbia Forest Service 1978).

REFERENCES

British Columbia Forest Service. 1978. Planning Handbook. British Columbia Forest Serv., Resour. Plan. Div., Victoria, B.C.

Navon, Daniel I. 1971. Timber RAM ... a long range planning method for commercial timber lands under multiple use management. USDA Forest Serv. Res. Paper PSW-70, 22 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Pearse, P.H. 1976. Timber rights and forest policy in British Columbia. Rep. Royal Comm. Forest Resour.

Williams, D.H., J.C. McPhalen, S.M. Smith, M.M. Yamada, and G.G. Young. 1975. Computer-assisted resource planning: an overview of the CARP project. [Unpublished paper on file at Fac. For., Univ. British Columbia, Vancouver]

Timber Management Planning with Timber RAM and Goal Programming

Richard C. Field

Abstract: By using goal programming to enhance the linear programming of Timber RAM, multiple decision criteria were incorporated in the timber management planning of a National Forest in the southeastern United States. Combining linear and goal programming capitalizes on the advantages of the two techniques and produces operationally feasible solutions. This enhancement may also be applicable to linear programming packages other than Timber RAM.

INTRODUCTION

In its timber management planning, the Forest Service, U. S. Department of Agriculture, often uses a linear programming (LP) package called Timber RAM (Resources Allocation Method) to calculate the potential yield under forest regulation. Regulation is defined as that future arrangement of forest treatments in space and time which achieves specified long-term objectives. The other part of timber management planning, harvest scheduling, is the treatment of existing forest conditions to achieve short-term goals and make some move towards the regulated condition. This planning phase is generally being carried out in some subjective, nonoptimal manner. I show here how goal programming (GP) might be used to improve the utility of Timber RAM for both forest regulation and harvest scheduling.

Timber RAM

To understand this paper, the reader must be somewhat familiar with the LP-based Timber RAM. Space does not permit a complete description here; for details on the Timber RAM package, see Navon (1971). Timber RAM is a set of computer programs which (1) generate input for any of several standard LP solution packages, and (2) produce final reports based on the input and the LP solutions. The latest versions of these programs are written for Univac 1100-series computers using the EXEC 8 operating system. However, the LP matrix generated for Univac's Functional Mathematical Programming System (FMPS) can also be solved using IBM's Mathematical Programming System (MPS). Timber RAM can also produce a matrix for solution by Univac's linear programming package ILONA. Earlier versions of Timber RAM are available for CDC and IBM computers.

Input data for Timber RAM include current stand conditions, projected yields of alternative treatments, regulation methods, harvest flow and budgetary constraints, regeneration possibilities and limitations, stand accessibility, and associated economic data and constraints. Different decision criteria can be entered by specifying indices of performance, such as volume, net revenue, and cost, with associated discount rates and periods of optimization. The user selects a single objective function for each desired solution of the LP problem.

In the United States, Timber RAM has been used primarily to maximize the short-run potential yields of western National Forests where there is a preponderance of overmature timber. Previously, these forests were regulated through use of volume control formulae. The linear programming with Timber RAM provided an improved approach (Hennes and others 1971). However, most of these applications of RAM were formulated as harvest scheduling problems, as is evident from the objective function, which is to maximize first decade harvest, and from the lack of constraints on the harvest flows after the forest is assumed to be regulated. Yet, budgetary constraints, such as are necessary for an operational harvest schedule, were also lacking. Hence, the solutions merely indicated the maximum yield that would be biologically and technologically possible during the short-term planning period, and did not provide a solution to the regulation problem.

In the southeastern United States, where the National Forests are generally understocked, area control has been used instead of volume control as the regulation method. Due to the relatively small contribution of the National Forests to southeastern timber supplies, Timber RAM has not been used in this region even though it can model the area control approach.

The Timber RAM system is adequately documented and fully supported by the Forest Service. For many National Forest planners, availability and convenience outweigh the inflexibilities of the system, enumerated by Chappelle and others (1976). Some of the technical drawbacks of RAM can be reduced by the procedures outlined in this paper.

New legislation regarding the National Forests implies, however, that managers must seek to achieve future conditions which are optimal and which insure regulation. These conditions will then limit all harvests, including those prior to the achievement of the regulated state. Strict area control cannot in general satisfy the constraints on harvest levels during conversion to the regulated state, and the other procedures currently in use do not adequately constrain to assure regulated conditions. This paper describes how Timber RAM, enhanced by GP, can be used to determine the required solutions to the timber management program.

Goal Programming

GP is a special form of LP suggested by Charnes and others (1955). It permits the simultaneous treatment of multiple objectives which may be incommensurate. Typical LP objective function rows are added to the constraint matrix as equalities. Right-hand sides that reflect the desired level of each objective are included, as are slack and surplus variables for each row. Then a new objective function composed of the slack and surplus variables of the former objective functions (the positive and negative deviations from the desired goals) is constructed and minimized by a standard LP algorithm. Differential weights greater than or equal to zero may be attached to the deviations to reflect the decisionmaker's value system.

Applications of GP to natural resources problems have generally used ordinally weighted deviations to effect a preemptive ranking of the goals, as described by Field (1973). In this study, however, cardinal weights were used to indicate relative values among goals rather than goal preferences. Rustagi (1976) used a similar approach in applying GP to forest regulation. This idea is extended here to include harvest scheduling by using GP to develop compromises between the several solutions available from Timber RAM.

METHODS

Timber RAM Input

Forest Data

The test area for this study was Oconee National Forest in the middle Piedmont of Georgia. In this forest of approximately 40,000-ha, about 80% of the area is in stands of loblolly pine (Pinus taeda L.) and short pine (P. echinata Mill.), and the remainder is in various mixtures of pine and several species of hardwoods. The pine stands are categorized by three classes of site productivity and nine classes of stand age or condition. The other stands (hereafter referred to as hardwoods) are categorized by only two productivity classes.

For each stand class and a variety of treatments, yields were estimated from published models, forest inventory data, and local timber sale data. Local forest policies dictated the type and range of activities that had to be evaluated. Generally, clearcuts at several ages, with or without prior thinning, were used for the pine whereas uneven-aged management with cutting cycles of two different lengths were used for the hardwoods. Local estimates of costs and revenues associated with harvest and regeneration were obtained. These forest data were then coded for use in Timber RAM.

Problem Constraints and Decision Criteria

The National Forest Management Act of 1976 and current Forest Service policy may be interpreted as prohibiting any harvest greater than the long-term sustainable average, and any harvest less than the level of any previous harvest. Indeed, the law seems to imply that a perpetually even flow of timber yield from the present cut henceforth is required. The law permits these constraints to be based on 10-year averages. Under these assumptions, the current cut is the lower bound for the initial harvest whereas long-term sustained yield is the upper bound on the initial and all subsequent harvests; and the intervening flows must be uniform or at least nondeclining. The law states that flow constraints may be relaxed only for consideration of other multiple use objectives. The requirement for even flows during the conversion to the regulated condition, it may be argued, may then be relaxed as necessary to achieve a high level of sustained yield, a possible multiple use objective.

Nondeclining and even flow constraints are easily incorporated in the Timber RAM model by using the option called "volume control and regulation" with "sequential lower bounds only." The lower bound must be set at zero for each control period during the time allowed for conversion to the regulated condition. The maximum yield permitted in the last control period of conversion must equal the postconversion average (long-term sustained yield). Fluctuation in 10-year yields cannot be permitted after conversion. For the Oconee forest application, limits were also placed on the expenditures and on the area harvested and regenerated in each decade by using Timber RAM's "interval constraints." Thus, harvest scheduling as well as forest regulation constraints were included in the same model.

The three decision criteria used for the Oconee application were the maximization of total volume and of present net revenue, and the minimization of total cost. These criteria covered the entire planning horizon of 150 years; economic values were discounted to the present at a 6% rate of interest.

Matrix Alternatives

The single LP matrix normally generated by Timber RAM from the input defining the problem is usually inadequate for planning. The planner may want to obtain solutions under different sets of constraints as well as different decision criteria. Also, certain modifications can improve efficiency of computation and others are required to implement the GP formulation. The following methods were used to create the necessary models for the Oconee National Forest.

Alterations during Matrix Generation

Two intermediate optimization problems were generated. The first was designed primarily to test the model. Here, all but one productivity class of pine was removed from the model and only clearcuts were permitted as management activities. The objective was to produce a small and generally predictable matrix. Solutions to this problem were obtained under the full range of constraint and objective variations discussed below. In addition, some matrix coefficients were systematically changed and postoptimality analyses were performed.

The second intermediate problem contained all the stand classes and constraints that were in the full problem, but the number of activities was reduced from 2229 to 228. For each basic variation of the full problem, a solution was first obtained with this abbreviated model. The solution was then used as an advanced basis to start the optimization phase of the full problem. This proved to be an efficient way to test solution procedures, and it shortened computation times for solutions to the full problem. Such an approach is useful when applying LP to any large problem.

Alterations after Matrix Generation

There are two ways to change a matrix already generated by Timber RAM. Simplest, but not necessarily most efficient, is to physically change, replace, add, or delete certain entries by editing. This procedure is useful for correcting a few errors in a small matrix. For a large matrix (the full problem in this application had 77442 elements) it is usually cheaper, but not necessarily quicker, to correct the raw input and generate a new matrix. Some form of editing or a programmed rewrite may be necessary for a large number of systematic changes which cannot be handled by these methods or others discussed below. Here, one FORTRAN program was used to generate test problem matrices with reduced yield coefficients, and another was used to create rows in the large matrix for certain GP models.

The best way to make temporary changes in an error-free matrix is with the standard "revise" and "modify" options in the LP package. Typical changes include relaxing certain constraints, changing right-hand sides, and adding or modifying rows for GP. Relaxing certain flow constraint rows not only provides useful information on trade-offs, but because the solution times are relatively short, is also another good way to test solution procedures. Other modifications successfully tested in this study are (1) creating objective functions not available from the Timber RAM matrix generator; (2) deleting redundant rows that occur with certain options; and (3) creating nonconstraining rows to facilitate reading the solution.

Goal Programming Formulations

In this application, two basic GP models were constructed. In the first, the three single-criteria optima (volume, net revenue and cost) from the LP models were the goals, and the sum of the underachievement of the volume and revenue goals and the overachievement of the cost goal was minimized. In separate variations of this model the deviations were equally weighted, weighted in favor of volume, and "relatively" weighted. In the last case each goal row was divided by the right-hand side (the goal) before the deviations were added. Thus, the sum of the relative or proportionate deviations from the goals as opposed to absolute deviations was minimized.

The second GP formulation minimized the sum of the deviation from the total volume goal and the deviations from each periodic volume flow goal. The original right-hand side of the constraint equation was used as the goal for each periodic flow. Thus, the objective function included the underachievement of the current cut by the harvest in the first period, the underachievement of the previous harvest by each subsequent harvest during conversion, the overachievement of the long-term average by the last harvest in conversion, and the over- and under- achievements of the long-term average by each post-conversion harvest. Variations in flow goals and economic goals, with a variety of weights, were tested only on the small problem.

Many other combinations of weighted goals and constraints can be formulated to best meet the planning needs of the decisionmaker. For goals that would normally be objectives in an LP model, simply add a right-hand side that is at least as large (or small) as can be attained with single objective optimization. Otherwise, the row should be a constraint. For goals that would be constraints in an LP model, the existing right-hand side or constraint is typically used. However, solutions to such problems should be carefully studied and compared to fully constrained, single objective solutions, especially if many or all the goals are achieved. There may be more acceptable solutions that are easily obtainable but go unrecognized in such goal formulations.

RESULTS

The results involve LP solutions, GP solutions, and postoptimality analysis of the small test problem. The LP set were obtained from Timber RAM using the procedures outlined above. The GP set is based on the reformulations of the Timber RAM matrix as GP models. The postoptimality results are based on LP and GP solutions for the single site, single rotation, and uniformly managed test problem.

Linear Programming Solutions

The first solution of interest used the standard Timber RAM criteria of volume maximization. Typically, if the solution was feasible and if the decisionmaker was happy with the harvest provided for the first decade (the short-term planning period), the analysis stopped there. In this case, however, the solution contained alternative optima which indicated that there are other strategies which meet the constraints and still give the same optimal objective value. This result implies that the analysis may not be complete because the procedure does not rank the strategies which can produce the optimum.

The solutions based on economic criteria also revealed some interesting conditions. The net revenue optimum was achieved by only one strategy, but the total harvest and long-term average were less than those provided by the maximum volume solution. A long-term yield less than the maximum, combined with the Forest Service's reluctance to use "profit" as a decision criterion, makes this solution less acceptable, even though it met all constraints. From a policy standpoint, cost minimization might be more acceptable, except that with this criterion only enough acres would be harvested to meet the current cut constraint. In the other two solutions the first period harvest was more than double the current cut. Consequently, none of these three solutions provided a completely acceptable basis for a timber management plan.

Goal Programming Solutions

Standard LP variations and postoptimality analysis might be able to improve single criterion solutions or show the "cost" of certain constraints. But, without reformulation or considerable external analysis, such procedures cannot effect the compromise between the alternative solutions that planning procedures usually require. GP provides for such a compromise. The solution using the optima from the three LP solutions as equally weighted absolute goals achieved the same long-term sustained yield as the volume maximization solution, as well as 96% of the maximum net revenue and 96% of the maximum volume for the planning period. There were no alternative optima in this solution.

Other goal formulations with differential weights would give different, but still feasible and conveniently determined solutions. When the deviation from the volume goal was given a weight of 10, while the others remained at one, the solution nearly achieved the volume goal. But the net revenue was higher than in the LP solution that maximized volume.

A formulation with equal weights on all goals carries implied weights in favor of the goals of larger numerical value. Relative weighting reverses this bias. Such effects were demonstrated in this application by the levels of achievement for the largest and smallest goals, revenue and cost, respectively. A solution using relative weights favored the cost goal. In this solution the current cost was just matched, as it was in the cost minimization solution, but many more acres were treated because of the influence of the volume goal.

Postoptimal Solutions

Sensitivity analyses to test the stability of certain solutions, given specified changes in inputs, were limited to the small problem. These iterative techniques are quite expensive when applied to large problems. However, the following results would seem to apply equally well to the large problem.

In the first set of tests, the sensitivity of the solution to changes in yield estimate was determined under the LP volume maximization criteria. A uniform change in current and future yields produced no change in the strategy that gives the optimum value of the objective function. Naturally, levels of periodic flows and total yields varied directly with changes in input.

It was next assumed that yield estimates for existing stands were correct and that the only changes that must be considered were for the yields of regenerated stands. New solutions then arose, but the activities selected for the first few periods were still unchanged. Similar results were obtained with the GP formulations. The stability of the preferred strategy reflects the dependence of early treatments and results on the conditions in existing stands. Recall that this analysis supports a short-term planning effort and that replanning and analysis will be required at relatively short intervals. Thus, considerable variation in long-term yield projections may not be detrimental to a typical timber management plan.

Postoptimality analysis was also used in the GP formulation to systematically change the weights on certain goal deviations. A wide range of solutions resulted, and indicated just how heavily a particular goal must be favored before it will dominate all others. For example, the volume goal required a weight 31 times those for harvest flow goals in order to approximate the LP optimum for volume without flow constraints.

CONCLUSIONS

Timber RAM may be attractive for the beginning forest planner, if the necessary computer facilities are available. It provides the basis for several approaches to forest regulation and scheduling of harvests on public lands. A land manager can employ some of the techniques presented here to enhance the application of Timber RAM. Simple reformulation as a goal model is within the capability of many users of RAM and helps to synthesize several satisfactory or nearly satisfactory solutions. The combination of LP and GP can also be useful with mathematical programming packages other than Timber RAM, including those used on privately owned lands. Finally, using GP in timber management planning sets the stage for multiple use planning because it provides the framework for the subsequent inclusion of other forest resources and products as additional objectives.

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LITERATURE CITED

Chappelle, D.E., M. Mang, and R.C. Miley. 1976. Evaluation of Timber RAM as a forest management planning model. J. For. 74:288-293.

Charnes, A., W.W. Cooper, and R.O. Ferguson. 1955. Optimal estimation of executive compensation by linear programming. Manage. Sci. 1:138-151.

Field, D.B. 1973. Goal programming for forest management. Forest Sci. 19:125-135.

Hennes, L.C., M.J. Irving, and D.I. Navon. 1971. Forest control and regulation: a comparison of traditional methods and alternatives. USDA Forest Serv. Res. Note PSW-231, 10 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Navon, D.I. 1971. Timber RAM -- a long-range planning method for commercial timber lands under multiple use management. USDA Forest Serv. Res. Paper PSW-70, 22 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Rustagi, K.P. 1976. Forest management planning for timber production: a goal programming approach. Yale School of Forestry and Environmental Studies Bull. 89, 84 p. New Haven, Conn.

Analytical Aids in Land Management Planning

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Abstract: Quantitative techniques may be applied to aid in completing various phases of land management planning. Analytical procedures which have been used include a procedure for public involvement, PUBLIC; a matrix information generator, MAGE5; an allocation procedure, linear programming (LP); and an input-output economic analysis (EA). These techniques have proven useful in the development of land management plans for a number of National Forests in the United States.

INTRODUCTION

The typical planning process used for developing land management plans follows a sequence of several phases. Although this overall process might be described in many ways, the major steps, shown in detail in Table 1, are (1) the identification of issues and objectives, (2) the development of the resource system and management options, (3) the analysis of tradeoffs, with the decision and feedback.

Various quantitative techniques may be applied to aid in completing these basic phases. The Systems Application Unit for Land Management Planning (SAU-LMP) of the Forest Service, U.S. Department of Agriculture, has utilized several types of analytical procedures in the successful development of land management plans for National Forests in the United States. Specifically, those used most often by SAU-LMP are a procedure for public involvement, abbreviated PUBLIC; a matrix information generator, called MAGE5; an allocation procedure, known as linear programming, LP; and an input-output economic analysis, called EA.

Table 1--The land management planning process

Systems Approach Terminology	Major Phases	Detailed Phases	SAU-LMP Analytic tools
	I. ISSUE IDENTIFICATION	Pre-Plan Organization	
		-Establish time frame for plan	
		-Establish personnel requirements for plan	
		-Define degree of public involvement	
Set Objectives	II. FORMALIZATION OF PLANNING	Identify Issues and Set Objectives	
		-Define critical issues and their source	
		-Define assumptions concerning decisions environment	PUBLIC
		-Define hierarchial set of goals	
		-Define criteria to be used to test performance	
System Design	III. DEVELOPMENT OF ALTERNATIVES	Define Resource System	
		-Stratify land base to address issues	
		-Designate management options	
		-Define resources and products	
		Define the Responses	
		-Identify information needs, sources of information and detail necessary	MAGE5
		-Determine resources and economic responses to management activities	
System Analysis	IV. ANALYSIS OF TRADEOFFS AND FORMULATION OF A RECOMMENDED PLAN	Analyze the Resource System	
		-Define the processes to be used in analysis	
		-Generate alternative management strategies	
		-Define tradeoffs between strategies	
		-Develop a scenario to describe tradeoffs	LP
		-Test each alternative in terms of meeting criteria of performance	EA

Decision and Feedback	Decision -Select a preferred alternative -Prepare a written plan directive and draft impact statement Feedback -Describe procedures for monitoring plan implementation and re vision when necessary -Insure tasks are carried out effectively and efficiently -Insure work plans are developed

PUBLIC

PUBLIC is the procedure used during the issue-identification and objective-setting phase to make quantitative estimates of public preferences and of conflicts among those preferences (Case and others 1976). The program is used at public workshops where the participants are asked to rank ordinally the uses of various National Forest resources from what "should be most emphasized" to what "should be least emphasized." PUBLIC is then used to analyze this input, to estimate agreement and disagreement in the total group, and to determine the least disliked priority ranking of Forest resource uses. The program constructs this ranking by creating an array of responses which indicate the "votes" for each preference. Then through a process of elimination, it assigns preferences to an order on the basis of whether a use preference receives either the majority of first-place votes or the majority of the "most disliked" votes. At the same time the procedure identifies subgroups which seem to have like interests or preferences. A statistical procedure, factor analysis, is used to subdivide the respondents into these subgroups. An estimate of the level of agreement within these subgroups is measured by the Kendal Concordance Coefficient. This is a statistic which generates on a scale of 0 to 1 a measure of subgroup agreement, 1 representing total agreement and 0 total disagreement.

This type of information is useful during the workshop session to group participants with like interests so they can work on specific alternative descriptions and resource-use levels or requirements. The procedure also supplies information which is useful for many different types of analyses to be conducted later, including comparisons of local preferences to overall regional preferences, comparisons of U.S. Forest Service staff preferences to local preferences, and analysis of public perception of agency priorities. Further, and most importantly, PUBLIC helps develop the type of public involvement information necessary to construct alternatives for analysis in subsequent phases of Forest level planning. The following table shows an ordering arrived at by means of PUBLIC:

Overall ordering entire workshop	Subgroup 1	Subgroup 2
Wildlife	Watershed	Wilderness
Scenic Beauty	Range	Scenic Beauty
Dispersed Rec.	Timber	Dispersed Rec.
Watershed	Wildlife	Wildlife
Timber	Dispersed Rec.	Range
Developed Rec.	Developed Rec.	Developed Rec.
Mineral Extraction	Mineral Extraction	Timber
Wilderness	Wilderness	Mineral Extraction

The preference patterns shown could be used to develop strategies which might be described in scenario form as:

> Strategy 1 (Overall ordering): Emphasize wildlife, scenic beauty, and dispersed recreation, with less emphasis on watershed, range, and timber, and give low priority to developed recreation, mineral extraction, and wilderness.
>
> Strategy 2 (Subgroup 1): Emphasize watershed, range, and timber, with less emphasis on wildlife, scenery, and dispersed recreation, and give low priority to wilderness, mineral extraction, and developed recreation.
>
> Strategy 3 (Subgroup 2): Emphasize wilderness, scenic beauty, and dispersed recreation, with less emphasis on wildlife, watershed, and range, and give low priority to timber, mineral extraction, and developed recreation.

These strategies could be used as part of the basis for construction goals and priorities for a Forest plan.

MAGE5

The next planning phase involves defining various aspects of the resource system. This phase of planning employs both the information concerning use preferences described above and information concerning the land base, to construct specific management options and resource uses for each of the management strategies previously identified. Once the management options have been determined, the consequences of each on the environmental resource, and the economic responses, must be defined. The U.S. Forest Service uses MAGE5, a matrix generator, to help the planner identify, develop, and store the necessary bits of information (U.S. Dep. Agric., Forest Serv. 1973). Since most plans cover a planning horizon of several years, one of the most significant benefits of using MAGE5 is that it allows for the time factor and attendant time changes in developing the appropriate dynamic data for the matrix. MAGE5 uses a concept called "timestreams" to adjust resource uses, benefits, and costs to changes which occur with time; it automatically constructs a matrix whose coefficients reflect this time dimension.

For example, suppose that the planning horizon is ten years subdivided into two periods of five years. A management option involving timber harvest might be applied either during the first period or during the second period. The values calculated for MAGE5 for the matrix rows and columns are as follows:

		Management option involving timber harvest applied in	
	Present condition	First period	Second period
Average sediment/ha/yr in the first period	0.4	0.64	0.4
Average sediment/ha/yr in the second period	0.4	0.68	0.64

Since the sediment yields are constant under present conditions in this land area, the average yields in each period are 0.4 cubic meter per hectare per year provided nothing changes. The average values for sediment yields where timber harvest is involved assume that the application of the option to an acre might occur at different years in the period. For example, the timber harvest might take place in any one of the five years of the first period. The various possibilities and the subsequent timestreams for sediment yield per year during the first period are as follows:

Option applied in	Year 1	Year 2	Year 3	Year 4	Year 5
First year	0.8	0.8	0.8	0.8	0.8
Second year	0.4	0.8	0.8	0.8	0.8
Third year	0.4	0.4	0.8	0.8	0.8
Fourth year	0.4	0.4	0.4	0.8	0.8
Fifth year	0.4	0.4	0.4	0.4	0.8

Note that if the option is not applied until a later year in the period, the present condition yield of 0.4 applies to all preceding years. The average value 0.64 for the sediment yield in the first period is the sum of the possibilities divided by their number, or 16/25 = 0.64. The other matrix entries are calculated in a similar manner, with the timestream depending on what period is being considered.

This concept is used to develop average yearly values for resource uses or commodities and for costs and benefits. These values are stored in a matrix format which can be utilized along with other tools, such as LP, which are used in later phases of the planning process.

LINEAR PROGRAMMING AND ECONOMIC ANALYSIS

Once the phases described so far are completed, the next step in the planning process is to analyze the resource system in order to determine how to allocate management options that best meet the preferences specified by the various strategies, and in order to identify the biological and socio-economic tradeoffs among strategies. In making these assessments the planner uses the information developed thus far in conjunction with two analytical aids: linear programming (LP) and an input-output economic analysis (EA). In the process of land management planning, a separate LP analysis is made for each management strategy so that the allocations which best meet the requirements and constraints stated for each strategy may be determined. For example, a separate analysis might be made for each of the three strategies specified earlier. Requirement levels are typically based on both the information developed in the earlier stage of public involvement and the kind of production of which the land is capable. Limiting factors might be such things as the number of acres available for possible options, the available budget, environmental constraints, and policy considerations such as nondeclining timber yield from the Forest. The objective functions might include such considerations as the maximization of present net benefits or minimization of costs over the term of the planning horizon.

The management options are selected on the basis of land suitability and in line with the public involvement process. There is usually a wide range of possibilities including wilderness management, big game management at various levels, various types of recreation management, and various kinds of timber management treatments. Each of these options might require a number of activities. For example, recreation management (type I) might require monitoring use, closing roads, and constructing trails.

A comparison must be made between LP results in order to show the tradeoffs among allocations, resource outputs, constraint levels, costs, and benefits. A good deal of additional information can be derived from the sensitivity or post-optimality analysis, which indicates how resource uses, constraints, and benefit values may change without affecting the LP optimal allocation. This is useful for a number of different purposes, such as determining what parameters may be most sensitive to changes in the plan and ascertaining whether additional inventory in certain areas may be appropriate.

The linear programming results are further utilized with the EA analysis package to estimate the impact which each of the possible strategies would be likely to have on local economic activity and employment levels (Palmer and Layton 1973). Given a particular strategy's predicted resource use or level of output, the EA analysis measures both the direct effects and the indirect or multiplier effect on various sectors of the local economy. This economic analysis results in a measure of the change in economic conditions likely to develop as a result of the application of a particular strategy. The significance of this impact depends, in part, on the magnitude of the change from what is the present condition and, in part, on the degree of influence this change has on the overall local or regional economy.

Table 2 is an example of the results of using the input-output portion of EA, which shows both the sectors affected directly and others which are indirectly affected as the impact of the change "ripples" through the economy. In the example, this effect amounts to $131,863 in total gross output. The EA package also estimates the effect the change will have on local employment according to individual occupation and month of the year.

Table 2--Sample results of using the input-output package of EA

SECTOR	FINAL DEMAND ($1000)	TOTAL GROSS OUTPUT ($1000)	CONSUMPTIVE WATER USE (ACRE-FEET)	LABOR MAN YEARS	INCOME $1000	VALUE ADDED $1000
1. AGRICULTURE	225.308	270.084	0.000	3.884	45.790	71.964
2. MINING	.001	.131	0.000	.003	.071	.106
3. CONSTRUCTION	9.339	13.495	0.000	.245	3.517	3.774
4. LOGGING	.005	.089	0.000	.004	.035	.049
5. SAWMILLS	.000	.206	0.000	.005	.045	.070
6. OTHER MANUFACTURING	.248	.321	0.000	.009	.088	.125
7. TRANSPORT & WAREHOUSING	.530	5.395	0.000	.179	2.114	2.902
8. COMMUNICATION & UTILITIES	3.742	14.806	0.000	.288	7.618	10.640
9. AUTO DEAL & GAS STATIONS	4.932	6.330	0.000	.427	4.265	4.855
10. EATING & DRINKING PLACES	3.056	3.291	0.000	.257	1.038	1.698
11. WHOLESALE & OTHER RETAIL	7.251	9.211	0.000	.544	5.378	6.200
12. FINANCE, INSUR. & R E	2.474	6.638	0.000	.267	3.669	5.571
13. LODGING	1.284	1.293	0.000	.051	.511	.701
14. SKI AREAS	.000	.000	0.000	.000	.000	.000

15. OTHER SERVICES	6.454	43.774	0.000	1.776	17.672	23.209
PRIVATE SECTORS, TOTAL	264.623	375.064	0.000	7.939	91.811	131.863
GOVERNMENT & MISCELLANEOUS		.000	0.000	1.553	.000	.000
TOTAL POP. 26.			0.000			
TOTAL	264.623	375.064	0.000	9.492	91.811	131.863

The linear programming and input-output results provide quantitative estimates of differences between strategies which can be used to illustrate tradeoffs as well as to demonstrate compatible relationships between possible alternatives. This type of information, because it is presented in easily understandable formats, is valuable for public presentations of the various strategies illustrating what might be expected when a particular plan is implemented. The public reaction to these strategies and tradeoffs is useful in developing a final plan which will be acceptable to the largest segment of the interested public.

APPLICATION

These techniques have proven successful in aiding in development of management plans for the Beaverhead, Willamette, Custer, Boise, Nezperce, Payette and Monongahela National Forests. In addition to being usable as a package for Forest plans, the techniques may be used individually for specific problems. For example, MAGE5 was used to help construct the area guides for U.S. Forest Service Rocky Mountain Region (R-2). EA is being used for a portion of the analysis necessary for the wilderness RARE II study. PUBLIC has been used in Alaska to develop local preference patterns and to compare these to preferences stated by Forest Service and Congressional representatives in Washington, D.C.

The programs have been used with UNIVAC and CDC computer systems. All these programs are coded in standard FORTRAN IV, and as such should be readily adaptable to other systems. Most of the problems related to National Forest applications have been solved through training and personal contact with technical staff provided at the Forest Service Regional Office or at the SAU-LMP in Fort Collins, Colorado.

The use of these quantitative techniques in planning provides for a comprehensive analysis of complex situations. The techniques offer an effective and efficient means to develop land management plans. They can handle information in large amounts, of differing types, and concerning diverse interrelationships between biological, social, and economic factors which would be impossible to deal with by any other means. The quantitative procedures used here offer a consistent, systematic approach to land management planning.

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REFERENCES

Case, Pamela J., Terry D. Edgmon, and Donald A. Renton. 1976. PUBLIC, a procedure for public involvement. Range Science Series 22, Colorado State University, Fort Collins. 138 p.

Palmer, Charles, and Ross Layton. 1973. Input-Output Analysis. Research Document, Economic Research Service. East Lansing, Michigan. 61 p. [Unpublished.]

U.S. Department of Agriculture, Forest Service. 1973. Resource Allocation Analysis, Users' Manual. [Unpublished]

Nutzwertanalyse

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Abstract: Nutzwertanalyse (NUWA) is a psychometric instrument for finding the best compromise in the multiple use planning of forestry, when the multiple objectives cannot be expressed in the same physical or monetary unit. It insures a systematic assessment of the consequences of proposed alternatives and thoroughly documents the decision process. The method leads to a ranking of alternatives based upon weighting of the objectives and evaluation of the contribution of each alternative to these objectives. The use of the method is illustrated with hypothetical data.

INTRODUCTION

In management planning of multiple use forestry the situation for the planner is as follows:

> Many possible alternatives must be compared in the light of a great number of more or less consistent or conflicting objectives (aims, goals) between which functional relations cannot be specified.
>
> In the process of comparing and assessing the consequences of the alternatives, it is unavoidable that the subjective preferences of the decision-maker and planner and of institutions play a vital role.
>
> Consequently, psychometric methods have to be introduced to obtain solutions corresponding to objectives which cannot be expressed in physical or monetary units.

To overcome these difficulties neither intuition nor mathematical models are of much help. In NUTZWERTANALYSE (NUWA) an instrument is at hand with which finding the best compromise can be made easier and more rational. The decision process will at the same time gain in clarity, and it will be reproducible in all its steps.

OUTLINE OF THE NUTZWERTANALYSE METHOD

The technique of NUWA consists of the following steps (see Abb. 1):

Step 1: The objectives (aims, goals) relevant to the situation are defined and arranged hierarchically according to means-objectives relations. At the end of the "chains of objectives" will be found "aims criteria" (Zielkriterien) K_j sufficiently precise to serve as the basis of analysis and evaluation.

Step 2: The weights g_j (Gewichte der Zielkriterien), i.e., the importance each objective shall assume in the process of evaluation, are given by the deciding authority according to its preferences.

Step 3: The consequences of each project alternative (alternative action) A_i with respect to each "aim/criterion" K_j are described in a matrix (Zielertragsmatrix). The elements E_{ij} of this matrix can be formulated in words or numbers.

Step 4: By "measuring" the consequences of the alternatives, each element E_{ij} is transformed into an element W_{ij} of the "value-matrix" (Zielwertmatrix). The scales (nominal, ordinal, or cardinal) by which the consequences are measured depend on the form and the precision of their description.

By these four steps the evaluation of an alternative has been divided up into m part evaluations, m being the number of criteria (objectives) to be taken into account.

Step 5: For each alternative A_i the NUTZWERT N_i is found by combining the weighted "values," according to a set of decision rules, which are consistent with the type of measurement scale used. The result (Nutzwertmatrix) gives ranking of the alternatives analyzed.

So NUWA may be briefly described as a method, with which a number of project alternatives are analyzed and assessed, with respect to a multidimensional system of objectives, by ranking the alternatives according to the preferences of the decisionmakers.

The following considerations in using NUTZWERTANALYSE may help to clear up some of the more difficult aspects:

System of General Objectives

The first requirement for using NUWA is to formulate a complete system of well-defined and carefully arranged objectives. In Abb. 2 you will find a "System of General Objectives in Forestry" which I presented in Oslo at the XVIth IUFRO Congress. These objectives are to maximize, minimize, conserve, promote etc., the criteria listed in Abb. 2. This system is only a first try and I hope a start for further joint efforts. Meanwhile in our country a guide for forest regional planning has been published that contains this system in a slightly different form.

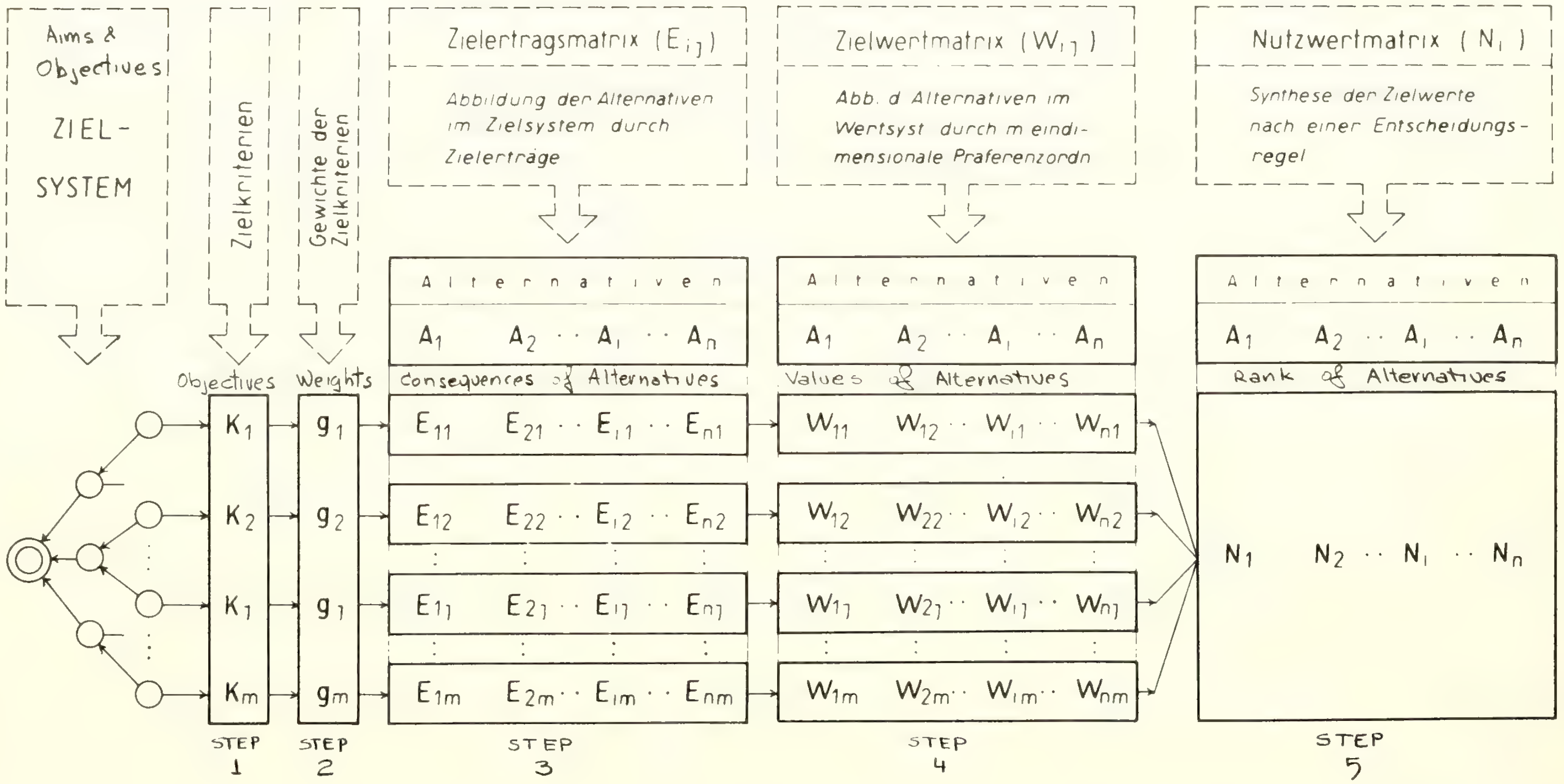
HESS. FORSTEINRICHTUNGSANSTALT

Nutzwertanalyse

Logische Struktur der Nutzwertanalyse

in Anlehnung an ZANGEMEISTER

Abb. 1

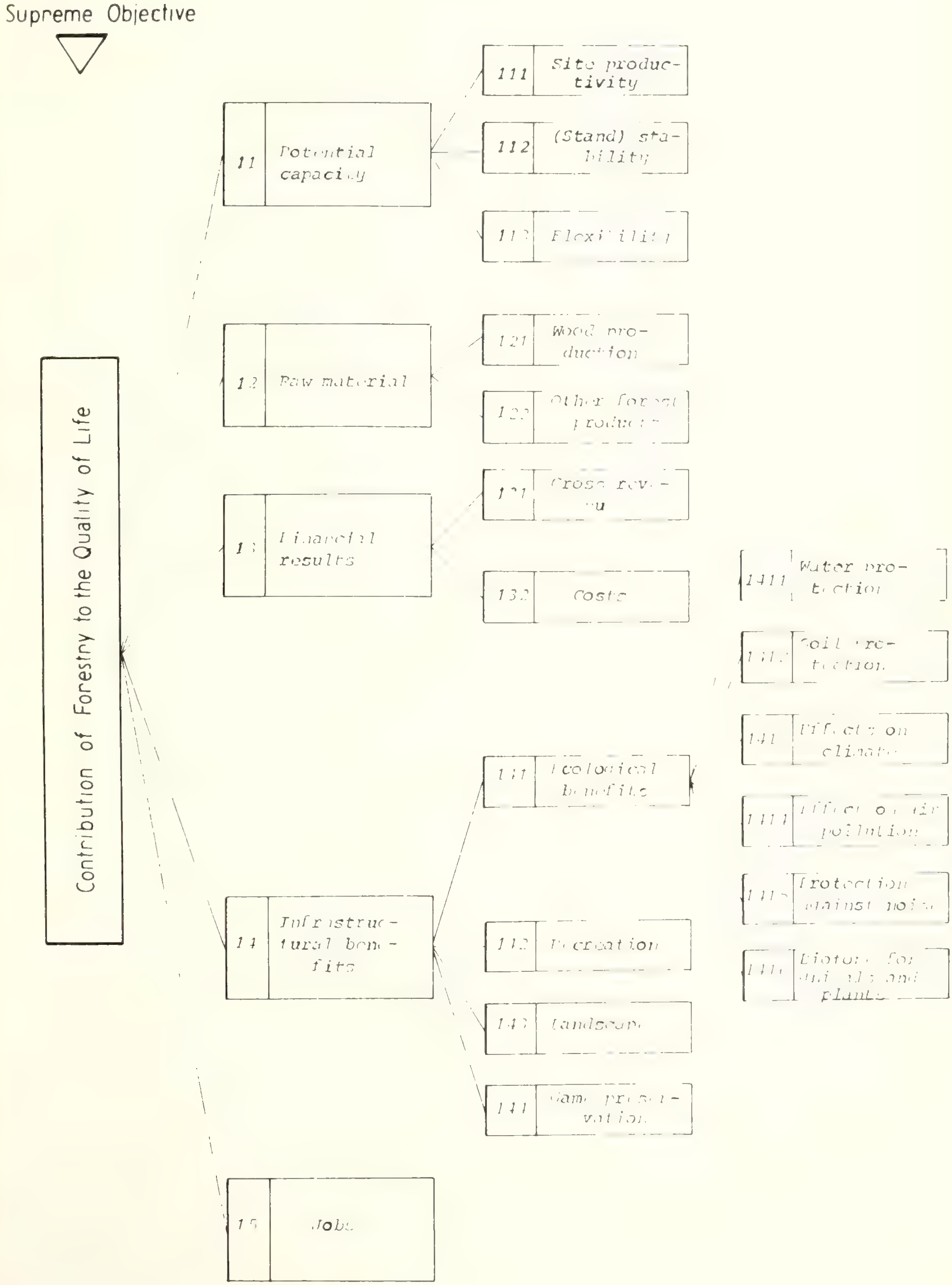

Aims & Objectives
ZIEL-SYSTEM
Zielkriterien
Gewichte der Zielkriterien
Zielertragsmatrix (E_{ij})
Abbildung der Alternativen im Zielsystem durch Zielerträge
Zielwertmatrix (W_{ij})
Abb. d Alternativen im Wertsyst durch m eindimensionale Praferenzordn
Nutzwertmatrix (N_i)
Synthese der Zielwerte nach einer Entscheidungsregel
Objectives
Weights
K_1 K_2 K_j K_m
g_1 g_2 g_j g_m
Alternativen
A_1 A_2 ·· A_i ·· A_n
Consequences of Alternatives
E_{11} E_{21} ·· E_{i1} ·· E_{n1}
E_{12} E_{22} ·· E_{i2} ·· E_{n2}
E_{1j} E_{2j} ·· E_{ij} ·· E_{nj}
E_{1m} E_{2m} ·· E_{im} ·· E_{nm}
Values of Alternatives
W_{11} W_{12} ·· W_{i1} ·· W_{n1}
W_{12} W_{22} ·· W_{i2} ·· W_{n2}
W_{1j} W_{2j} ·· W_{ij} ·· W_{nj}
W_{1m} W_{2m} ·· W_{im} ·· W_{nm}
Rank of Alternatives
N_1 N_2 ·· N_i ·· N_n
STEP 1
STEP 2
STEP 3
STEP 4
STEP 5

FEA - GIESSEN

Nutzwertanalyse

System of General Objectives in Forestry

Abb. 2



Weights of Objectives

An example for step 2--the "weighting" of the objectives--is given in Abb. 3. Using the presented system of objectives, the weighting is simulated for the state forests of Hessia, using the method of "pairwise comparison." You find the preliminary weights calculated in percentage numbers in column (3) of the table. After a transformation by means of an interdependence factor, the final general weights are given in column (6) of the table. (These numbers correspond to the weights g_j (Abb. 1). A detailed description of the method is given in another paper by the author (Henne 1976). Other methods are described in Zangemeister.

Evaluation Scheme

In forest management planning certain types of planning situations constantly recur, e.g., planning the treatment of a stand to be harvested and regenerated (see the following simulation). In such a case an evaluation scheme (Abb. 5) for use in all similar situations can be prepared, in which step 3 and 4 of the NUWA logic are combined and systematized: the possible consequences of alternatives are put in increasing order and a corresponding scale is put above the resulting matrix (in Abb. 5 a cardinal scale is used). With respect to only four "objectives" can the consequences of the alternatives can be measured in numerical units: wood production in cubic meters, gross receipts, costs in marks, and amount of labor in hours. In all other cases only qualitative descriptions can be given--for the time being. The vagueness of these descriptions and even some blanks show the field of research yet to be cultivated before intuition can be efficiently replaced by rational thinking in complex planning situations.

Simulation of a NUWA

One of the most important tasks in medium and long-term multiple use management planning of unevenaged forests is to decide

When and how to cut a mature stand,

How and with what species to regenerate the cleared area.

In Abb. 4 a planning situation of this kind involving five silvicultural alternatives (A_1 - A_5) is analyzed. You will find the following information:

In column 1 the objectives, drawn from the System of General Objectives in Forestry presented in Abb. 2

In column 2 the general weights of these objectives, drawn from column 6 in Abb. 3

In column 3 a transformation of the general weights to account for local conditions, and in column 4 the corresponding normalized value of these adjusted weights.

HESS. FORSTEINRICHTUNGSANSTALT

Nutzwertanalyse

Weighting of Objectives

Using the method of "pairwise comparison" (KOELLE)

Abb. 3

Is the objectivebelow more or less important *) than the objective here

*) Scale reaching
from +5 = very much more import.
0 = equally important
to −5 = very much less important

		Site productivity 111	(Stand) stability 112	Flexibility 113	Ecological benefits 141	Recreation 142	Landscape 143	Wood production 121	Gross revenue 131	Work conditions 152	Jobs 151	Costs 132	Other forest products 122	Game preservation 144	Sum line ①	Col. 1+(13−1) x 5 ②	Preliminary general Weight (Col. 2 ÷ 0,780) ③	Interdependence factor ④	Final general Weights Col. 3 x Col. 4 ⑤	Normalyzed general weights Col. 5 ÷ 1,023 ⑥
111	Site productivity		0	+1	+1	+2	+2	+3	+3	+3	+4	+4	+4	+5	+32	92	11,8	1,016	12,0	11,7
112	(Stand) stability	0	—	0	+1	+2	+2	+3	+3	+3	+4	+4	+4	+5	+31	91	11,7	1,295	15,2	14,9
113	Flexibility	−1	0		0	+1	+1	+2	+2	+3	+3	+4	+4	+5	+24	84	10,8	1,131	12,2	11,9
141	Ecological benefits	−1	1	0		+2	+2	+3	+3	+3	+4	+4	+4	+5	+28	88	11,3	0,918	10,4	10,2
142	Recreation	−2	−2	−1	−2		+2	+2	+3	+4	+4	+4	+4	+5	+21	81	10,4	0,935	9,7	9,5
143	Landscape	−2	−2	−1	−2	−2		+1	+1	+2	+2	+3	+4	+5	+9	69	8,8	0,984	8,7	8,5
121	Wood production	−3	−3	−2	−3	−2	−1		+2	+2	+3	+3	+4	+5	+5	65	8,3	0,951	7,9	7,7
131	Gross revenue	−3	−3	−2	−3	−3	−1	−2		0	+1	+2	+4	+5	−5	55	7,1	0,869	6,2	6,1
152	Work conditions	−3	−3	−3	−3	−4	−2	−2	0		+2	+3	+4	+5	−6	54	6,9	1,049	7,2	7,0
151	Jobs	−4	−4	−3	−4	−4	−2	−3	−1	−2		+2	+4	+5	−16	44	5,6	0,967	5,4	5,3
132	Costs	−4	−4	−4	−4	−4	−3	−3	−2	−3	−2		+4	+5	−24	36	4,6	1,049	4,8	4,7
122	Other forest products	−4	−4	−4	−4	−4	−4	−4	−4	−4	−4	−4		+2	−42	18	2,3	1,000	2,3	2,2
144	Game preservation	−5	−5	−5	−5	−5	−5	−5	−5	−5	−5	−5	−2	—	−57	3	0,4	0,836	0,3	0,3
		−32	−31	−24	−28	−21	−9	−5	+5	+6	+16	+24	+42	+57	0	780	100,0	13,000	102,3	100,0

FEA-GIESSEN **Nutzwertanalyse**	Example of a Nutzwertanalyse Regeneration of a Beech Stand (130 years)	Abb. 4

1		2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Objectives		weights			Value of Alternatives						Teilnutzwerte (Col. 6 ..... 10x Col. 4)					
		General weights Abb. 3 Col. 6	Local weights	Normalised local weights (Col. 3 : 0,978)		Leaving the beech stand for another 40 years, then Dougl.f.	Nat. regen. of beech, compl. by planting Larch + Norway spr.	Clear cutting, planting of Norway spruce	Clear cutting, planting of Douglas fir	Clear cutg., pl. of Dougl. fir, along road gradual reg. by select. cutting						
						A 1	A 2	A 3	A 4	A 5		A 1	A 2	A 3	A 4	A 5
111	Site productivity	11,7	11,7	12,0		9	10	7	6	8		108	120	84	72	96
112	(Stand) stability	14,9	14,9	15,2		5	9	4	2	5		76	137	61	30	76
113	Flexibility	11,9	11,9	12,2		10	8	2	1	3		122	98	24	12	37
1411	Water protection	10,2	–													
1412	Soil protection		–													
1413	Effects on climate		1,0	1,0		5	5	5	5	5		5	5	5	5	5
1414	Eff. on air pollution		–													
1415	Protection against noise		2,0	2,0		3	6	5	4	7		6	12	10	8	14
1416	Biotope for animals a. plants		1,0	1,0		8	10	3	1	6		8	10	3	1	6
142	Recreation	9,5	12,0	12,3		7	10	5	4	7		86	123	62	49	86
143	Landscape	8,5	10,0	10,2		7	10	6	5	8		71	102	61	51	82
121	Wood production	7,7	7,7	7,9		8	5	10	7	8		63	40	79	55	63
13	Financial results	6,1	6,1	6,2		6	3	10	8	8		37	19	62	50	50
152	Work conditions	7,0	7,0	7,2		9	4	9	9	8		65	29	65	65	58
151	Jobs	5,3	5,3	5,4		4	6	10	9	7		22	32	54	49	38
132	Costs	4,7	4,7	4,8		10	6	3	4	5		48	29	14	19	24
122	Other forest products	2,2	2,2	2,3		3	1	10	5	9		7	2	23	12	21
144	Game preservation	0,3	0,3	0,3		5	5	3	3	8		2	2	1	1	2
		100	97,8	100			Nutzwert ▷					726	760	608	479	658
							Rank ▷					2	(1)	4	5	3

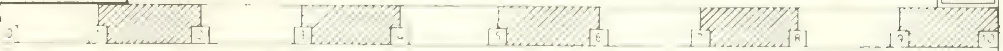
HESS. FORSTEINRICHTUNGSANSTALT

Nutzwertanalyse

Evaluation Scheme

Methods of Regeneration and Choice of Species

Abb 5



Value of alternatives → Objectives ↓		1–2	3–4	5–6	7–8	9–10
[illegible]	[illegible]	[illegible]				
[illegible]	[illegible]	[illegible] influence	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	very [illegible]
11	[illegible]	[illegible] difficult and expensive	[illegible] dependent on [illegible] the next generation			conver[illegible], several alternatives, [illegible] option in the next [illegible]
121	Wood production	mean annual volume increment [illegible]				
		[illegible] – 3,5	3,5 – 7	7 – 10,5	10,5 – 14	14 – 17,5
12	other forest products	[illegible]				
		[illegible]	[illegible]	[illegible]	[illegible]	very [illegible]
131	Gross revenue	[illegible]				
		[illegible] – 240	240 – 480	480 – 720	720 – 960	960 – 1200
13	Costs	[illegible]				
		50 – 80	80 – 110	110 – 140	140 – 170	170 – 200
1411	Water protection	[illegible]				
		very unfavourable	unfavourable	[illegible]	favourable	very favourable
1412	Soil protection	[illegible]				
		very low	low	[illegible]	[illegible]	very high
1413	Effects on climate	[illegible]				
		very unfavourable	unfavourable	neutral	favourable	very favourable
1414	Effect on air pollution	limited to certain seasons, missing during regeneration phase	limited to certain seasons, reduced during regeneration phase	[illegible]	[illegible]	very high in all age classes and during most of the year
1415	Protection against noise					
1416	Biotope for animals and plants	number of [illegible]				
		very low	low	average	high	very high
142	Recreation	open for activities during lesser part of rotation, no shelter by old trees in regeneration phase, snow cover higher and longer, no sunlight in winter				open for activities during greater parts of rotation, shelter by old trees even during regeneration phase, seasonal change between shadow and sunlight
143	Landscape	monotony with regard to tree species, age, stand structure etc.; prevailing of "unaccustomed" species, no transparency of stands				harmonious change of tree species, age classes, stand structure, silvicultural intensity, prevailing of well known species, transparency of stands
144	Game preservation	as habitat for game on the average				
		hardly qualified	less qualified	normally qualified	well qualified	highly qualified
151	Jobs	mean annual volume of work, hours per ha				
		2 – 5	5 – 9	9 – 12,5	12,5 – 15,5	15,5 – 19
152	Work conditions					

In columns 6 ... 10 the value matrix for the five alternatives obtained by applying the given evaluation scheme

In columns 11 ... 16 the "Teilnutzwerte" found by multiplying the values in columns 6 ... 10 with the "local" normalized weights drawn from column 4

At the foot of columns 11 ... 16 the "Nutzwerte" of the alternatives, ranging from 479 to 760, calculated by summing up the corresponding column of Teilnutzwerte

The alternative with the highest numerical value A_2 is assigned rank 1. This alternative will yield a mixed stand of deciduous trees and conifers, produced by natural regeneration of the existing beech stands, using a shelterwood method, supplemented by planting larch and spruce.

This solution is the best compromise under the local conditions, the area being part of a nature park on the border of the Rhine-Main-Industrial Region. A look at columns 11 to 16 in the "Teilnutzwerte" (Abb. 4) shows which objectives contribute the most points to the "Nutzwert" of A_2.

On the one hand it is the high importance attributed to the objectives of site preservation, stability and flexibility, in which the principle of sustained yield--of all the benefits of forests--is reflected. On the other hand it is the importance of recreation and landscape under the special circumstances of the example.

CONCLUSIONS

In conclusion, I hope I have been able to show not only how much more transparent the decision processes can become by using NUWA, but also how much weight the ecological, hygienic and aesthetic objectives are given in the silviculture and forestry of our country.

LITERATURE CITED

Henne, A. 1976. Ziele, Zielgewichte und Nutzwertanalyse in der mittelfristigen forstlichen Planung. Allg. Forszeitschr. 32.

Zangemeister, C. Nutzwertanalyse in der Systemtechnik. Wittemannsche Buchhandlung, Munchen, Gesim.

See for additional reference:

Gundermann, E. 1972. Untersuchungen sur Erfassung, Wertung und Ordnung der Erholungsfunktion von Waldbestanden im bayerischen Hochgebirge. Forschungsberichte der Forstl. Versuchsanstalt, Munchen.

Henne, A. 1972. De Sozialfunktionen des Waldes in der mittelfristigen forslichen Planung. Allg. Forstzeitschr. 24.

Jacob, H. 1973. Zur Messung der Erlebnisqualitat von Erholungswaldbestanden. Beiheft 9 zu Landschaft und Stadt, Ulmer Verlag.

A Methodology for Decisionmaking in Project Evaluation in Land Management Planning

A. Weintraub

Abstract: In order to evaluate alternative plans, wildland management planners must consider many objectives, such as timber production, recreational use, and community stability. The method presented utilizes the type of qualitative and intuitive information widely available to wildland management planners, and structures this information into a format suitable for decisionmaking. The method makes possible the determination of a measure of overall desirability for alternative plans, and permits the evaluation of plans under alternative value systems. Alternatives are compared through a small set of values assigned to each one. Each number in the set represents a measure of desirability not directly comparable to the others. The planner assigns weights to each measure and obtains a unique number for each alternative. The method is simple to use and flexible, to permit modifications as planners gain expertise in its use.

INTRODUCTION

The method proposed consists of a set of steps which provide a structured framework for choosing among alternatives, when multiple objectives or criteria have to be considered, and uncertainty exists. At each step, the method provides for the participation of decisionmakers, specialists, analysts, and possibly, the general public.

The scheme requires the limited participation of decisionmakers and deviates little from generally used organizational patterns. Several concepts which are essential for correct and efficient evaluation are emphasized:

(a) Screening, which allows the elimination of alternatives simply on the basis of "rough cut," general evaluations.

(b) Evaluation of the accuracy and certainty of information used in the determination of the impacts of the alternatives.

(c) Reduction to a manageable number of the impacts necessary for the evaluation of alternatives.

(d) Visual presentation of results in tables and "scoreboards" which present information to the decisionmaker and to the public in a clearer way and with a simpler format of analysis.

(e) Generation of potentially attractive new alternatives, through modification and combination of already defined alternatives.

Concepts (c) and (d) are essential in presenting the decisionmakers with a clear summary of the impacts with respect to the declared goals. Note that with this scheme there is no need for the decisionmaker to specify his utility function or explicit preferences. Although these weights simplify the selection of the preferred alternatives, they introduce serious methodological complications rooted in the complexity of utility functions.

The scheme is applicable to a broad range of planning problems. It is presently being used in the decision process for a recreation area project (skiing and summer activities) in the Tahoe National Forest, in California. The main goal of this project is to provide recreation facilities to satisfy increasing demand in a location with very attractive possibilities. The site will be developed by private capital, but a large percentage of the land needed belongs to the Forest Service, U.S. Department of Agriculture. As a public agency, the Forest Service must consider, when evaluating alternatives, the preservation of environmental quality, as well as the socioeconomic impacts a recreation complex will have on neighboring communities.

The steps of the scheme will be illustrated with examples, most of which are drawn from this recreation project.

THE SCHEME

The basic steps are the following:

1. Define the boundaries of the problem: the area of study, the types of alternatives to be considered (e.g., Area--Tahoe region; Types of alternatives--develop recreation facilities for winter use or for winter and summer use).

2. Identify decision-influencing elements, criteria, or goals. Goals can be defined at different levels of aggregation: (1) a general goal, such as to preserve environmental quality, which can be refined into (a) preserve air and water quality, (b) maintain wilderness, etc.; or (2) a primary goal, such as to enhance social well-being of the population, and secondary goals such as (a) promote acceptable patterns of employment, (b) avoid overcrowding of services, etc.

3. Identify major forms of activities and areas in which they can be carried out (e.g., logging and range in unit A).

4. Define basic alternatives to be considered (e.g., alternatives emphasizing recreation, logging, preservation of wilderness, etc.)

5. Define the major types of impacts of each alternative in relation to the goals established. Include secondary effects only if they are important.

6. Screen the alternatives. Determine a set of criteria which would make an alternative unacceptable. Based on these criteria, find which alternatives can be eliminated without additional collection of data or finer analysis (e.g., general analysis may be sufficient to determine that a practice of intensive timber cutting in a given area results in unacceptable environmental and recreation impacts. Then, any alternative with that practice would be screened out). Screened-out alternatives will be reconsidered later in the light of the additional insights gained from the analysis.

7. For those alternatives passing the screening process, determine their impacts in a disaggregated and quantified form in relation to the declared goals. Several models can be used for estimating partial impacts (i.e., econometric models to predict ski demand, input-output models for estimating income and employment effects, etc.).

Impact information can appear in different forms:

(A) Hard information: data which is quantified, relatively accurate and certain.

(B) Nonquantifiable information: impacts which may be estimated from accurate and certain input-output data, but which are expressed as qualitative ratings and therefore depend on subjective evaluation (e.g., the acreage and condition of wilderness and scenic areas may be known but the impact of management alternatives can only be assessed intuitively).

(C) Soft information: insufficient information exists about conditions or about the consequences of management (e.g., impacts on timbered areas where no appropriate survey has been made).

(D) Uncertain information: impacts that cannot be predicted with precision. The sources of uncertainty may be:

   (a) Uncertainty about the "future of the world" (e.g., what is going to be the rate of increase on overall demand for recreation in the future).

   (b) Technical uncertainty in projections, that is, the impossibility of predicting exact impacts, even if the setting in which they occur is known with certainty.

   (c) Uncertainty about the implementation of each phase of the project exactly as it is defined in the study.

8. Reduce the number of impacts to be considered in this evaluation for each alternative by discarding and aggregating impacts according to the goals established.

This step is needed to reduce the normally large number of impacts generated in Step 7 to a much smaller number of representative impacts, which will make the evaluation process in relation to the declared goals more manageable.

The reduction of impacts to evaluate is accomplished by eliminating from consideration the impacts which are not likely to affect the decision (i.e., exclude impacts of negligible importance, or those that do not vary much among the alternatives), and aggregating sets of impacts into one representative of the set which may be quantified through an index (i.e., aggregate into one those impacts which may be considered as one goal or subgoal, such as different measures of water quality, or which are highly correlated under all alternatives, such as wilderness and wildlife impacts).

The elimination and aggregation process may be modified as new alternatives are generated. Control over this process can be maintained by reverting to Step 7 at any stage.

9. Check the legal, institutional, environmental, political, and economic acceptability of each alternative.

The detailed and aggregated information of Steps 7 and 8 allows for this analysis, which can be carried out according to the specifics of the situation. For example, a disaggregated impact of Step 7, such as air pollution measures, allows a check for compliance with legal requirements, while the aggregated use of impacts of employment, in housing and community services, regional economy, etc., facilitate a political evaluation of the alternatives.

10. Generate new, potentially attractive, basic alternatives which are significantly different from those already proposed, and return to Step 6. This step can be carried out through major mitigating actions (modifications of alternatives) or by combination of "good" elements of alternatives already specified.

The steps for generating new alternatives are these:

(A) For each basic alternative, describe the main actions and their location.

(B) For each action evaluate the main positive and negative impacts on the defined goals. Also analyze composite effects of the global project.

(C) For each impact, determine which changes in primary conditions would reduce negative effects, or increase positive effects.

(D) For changes in primary conditions which would improve impacts, determine which actions would bring about those changes and what are the trade-offs implied (i.e., which other impacts are also affected through those actions).

(E) (a) For major mitigating actions, determine which actions have acceptable trade-off to improve impacts. Generate new alternatives introducing these actions.

(b) For combination of alternatives, determine, for two or more alternatives studied, which actions lead from one to another in some aspects. This procedure is used to determine combinations of elements of each alternative to generate a new one.

Alternatives generated must be technically and economically feasible.

A partial example of the procedure is the following:

(A) Basic alternative: one action is to build a large ski facility in a designated area.

(B) One negative effect: overflow of visitors from the area in winter creates serious social problems in neighboring communities.

(C) This negative impact can be mitigated by reducing the number of people going into the neighboring towns.

(D) Actions which would bring about this reduction are to reduce the size of the planned ski facility or to increase substantially the lodging and eating facilities in the recreation complex (to keep visitors in the area).

(E) Consider a major mitigating action with a substantial increase in lodging and eating facilities. The trade-off of this action, which in this case consists of additional negative impacts, is increased water usage, waste disposal problems, reduced attractiveness of the resort, reduced profitability of the project. If the trade-off seems acceptable, a new basic alternative can be generated incorporating the new lodging and eating facilities.

11. Determine if new areas of concern or types of impacts need to be defined. If yes, go back to Step 6 and check alternatives. This step acts as a control, as new knowledge is gained in the process.

12. Present the summarized results in adequate visual format. Impacts will be presented in tables by indexes (expected values and ranges will be used). Colors may be used to highlight differences among alternatives. See tables 1 and 2 as examples.

These tables show visual presentation possibilities for the described recreation project, for three proposed alternatives--A, F, and G.

A: Accept a project proposed by the Walt Disney Corporation to build a large winter and summer recreation complex in a designated area.

F: Leave the designated area untouched, promote the expansion of existing recreation sites.

G: Call for bids for a smaller recreation complex in the designated area.

Table 1. Reduced Impact List

Impact	Alternatives		
	A	F	G
Environmental			
Overall Physical-Biological	(-2,-3,-5)	(0,-1,-2)	(-1,-2,-3)
Water, Air, Waste	(-7,-8,-9)	(-2,-3,-4)	(-4,-5,-6)
Effect on Tahoe Basin	(+3,+4,+6)	(-3,-5,-6)	(+1,+2,+3)
Economic			
Impact neigboring counties	(+5,+6,+8)	(-1, 0 0)	(+2,+3,+4)
Economic feasibility	(+5,+7,+8)	(+2,+2,+3)	(+1,+3,+4)
Regional, Tahoe Basin impact	(1,+2,+2)	(+1,+2,+2)	(0,+1,+1)
Social			
Pressure on social structure, Traffic congestion	(-5,-6,-9)	(-1,-1,-2)	(-3,-5,-6)
Pressure on services, controllability of growth, distribution of negative effects	(-3,-4,-6)	(-2,-3,-4)	(-1,-2,-3)
Effect in Tahoe Basin	(+2,+3,+5)	(-6,-7,-9)	(+1,+2,+3)
Recreation			
Winter	(6, 8 8)	(4, 5 6)	(3, 4 5)
Summer (include wilderness recreation lost)	(4, 5 6)	(0)	(1, 3 4)
Effect Tahoe Basin	(2,+4, 5)	(-3,-5,-6)	(+1,+2,+3)
Institutional			
Effect on other FS activities	(-3,-4,-5)	(-1)	(-1)

Table 1 is a list of main impacts. Impacts are rated from 0 to 10 for positive impacts, 0 to -10 for negative impacts (+10, -10 correspond to the most positive and the most negative respectively). In each case, the circled number corresponds to the expected value of the impact, the other two represent the range due to uncertainty. (Note: creating a recreation complex in the designated area will take away pressure from the Tahoe basin). Colors (not shown in table) are used to highlight differences, e.g., most positive values are circled in blue, next values in green, etc.

Table 2--Impact list with information about causes of uncertainty

The main causes of uncertainty are:

1 Growth of Reno (Reno is a fast-growing city, with high tourism, which shares with the designated area the freeway linking to the main population center in the region, the San Francisco Bay Area.)

2 Secondary impacts on neighboring counties

3 growth of overall recreation (ski) demand

□ not sufficient information (soft information)

Δ technical incertainty

<table>
<tr><th rowspan="2">Impact</th><th colspan="3">Alternative</th></tr>
<tr><th>A</th><th>F</th><th>G</th></tr>
<tr><td>Environmental</td><td></td><td></td><td></td></tr>
<tr><td>Overall Physical-Biological</td><td>|-3||</td><td>|-1|</td><td>|-2|</td></tr>
<tr><td>Water usage</td><td>③|$\overset{\Delta}{-}8$||②</td><td>|-3|</td><td>③||-6|②</td></tr>
<tr><td>Waste disposal</td><td>③|-8|②</td><td>||-3|</td><td>③||-5|②</td></tr>
<tr><td>Air quality</td><td>③|-7||①
②</td><td>|-4||①</td><td>③|-5||①
②</td></tr>
<tr><td>Effect on Tahoe Basin</td><td>③||+4|
□</td><td>③||-5|
□</td><td>|+2|
□</td></tr>
</table>

In this case, water usage for alternative A for example is: ③|$\overset{\Delta}{-}8$||② and is equivalent in Table 1 to (-7,(-8),-10). The information provided is:

② If secondary impact is larger than expected, water usage impact tends to grow in absolute value.

③ If ski demand is less than expected, water usage impact tends to decrease in absolute value.

Δ There exists technical uncertainty in the projection.

Table 2 is a more detailed list of impacts in a different format. The number between vertical lines represents the expected impact. The number of vertical lines indicate the level of uncertainty in each direction, and the circled numbers refer to notes on the causes of this uncertainty.

13. Evaluate alternatives presented in Step 12. Determine the most attractive alternatives (or the better alternatives). To make this determination, sensitivity analysis should be carried out on uncertain, soft, or nonquantified data. Sensitivity analysis should include two aspects.

(a) The analysis of the stability--or robustness--of solutions. For example, an alternative may look very attractive when expected values are considered. However, once uncertainty is included, it may look much less desirable, due to a high probability of the least desirable outcome.

(b) The indication on where more and better information is needed, for sound decisionmaking. For example, an estimate with 15% error in the projection of timber demand may be sufficient in some cases. In others, a finer estimate may be crucial in the decision as to a project's financial soundness.

The overall impact of each alternative should also be considered; that is, besides a comparison of each attribute, it is important to view the global effect of the alternatives, and to include the intangible impacts in this assessment.

If none of the alternatives selected appears completely satisfactory, study what new aspects should be considered to generate new alternatives (i.e., new decision-influencing elements, criteria to improve overall impact or evenness of alternatives, criteria to reduce uncertainty, etc.). Then go back to Step 5. Otherwise continue to Step 14.

14. Generate new potentially attractive alternatives, marginally different from the ones selected in 13. This is done through proposing minor mitigating actions or combination of characteristics of the (similar) alternative selected. The mechanics of this step are similar to Step 10, where now detailed characteristics are considered. A minor mitigating action might be a small modification in the time stream of timber logged, to provide a more even supply to nearby mills. Alternatives generated at this stage should be technically feasible and economically efficient. Go back to Step 7. If no new alternative is generated, go to Step 15.

15. Select preferred alternative.

CONCLUSION

The scheme presented here has been well received by the professionals in charge of the Tahoe National Forest recreation project, and is currently being used in the decision process.

The scheme allows for flexibility, and some variations may be recommended in different applications. It can be used effectively in a variety of planning situations. For example, for the Tahoe project it was determined that the screening process--Step 6--should be introduced after Step 9 to permit a thorough evaluation of the major impacts for every alternative. This was done in order to avoid the adoption of intransigent opposition by interest groups whose preferred alternative might be screened out.

The method presented is designed to be used for land management planning, e.g., alternatives which emphasize the multiple use and value of land: timber, range, recreation, wilderness, ecology, etc. This form of decisionmaking is somewhat different from the evaluation and selection of single projects, as in the case of the recreation project, since it involves the determination of a combination of different forms of activities on areas with diverse characteristics which will make up a land management plan for a forest or land unit. This multiplicity of activities allows for a richer variety of possibilities in combining elements forming a plan and must be considered particularly in Steps 3, 8, 10 and 14.

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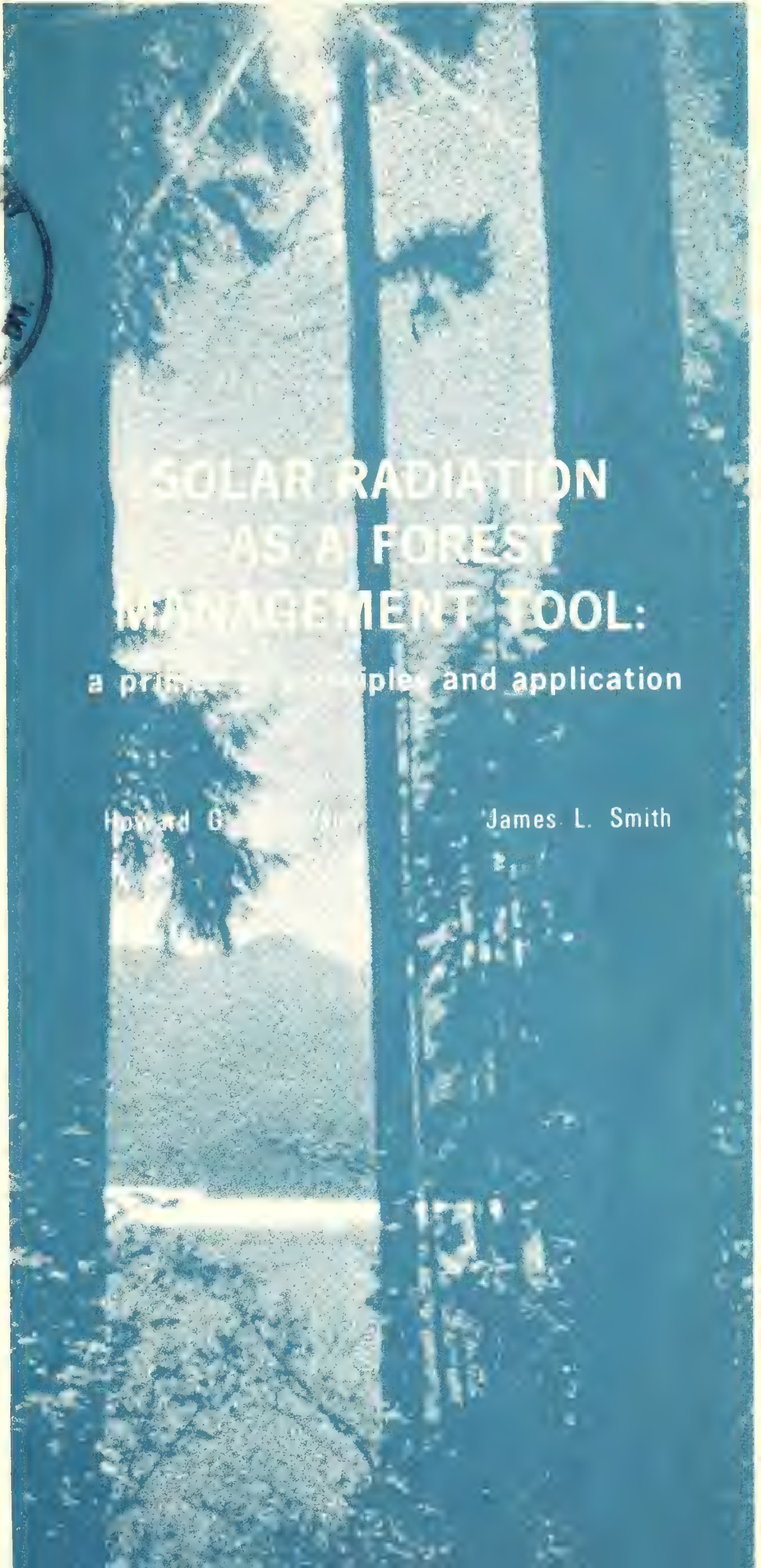

SOLAR RADIATION AS A FOREST MANAGEMENT TOOL:

a primer of principles and application

Howard G.
James L. Smith

GENERAL TECHNICAL
REPORT PSW- 33

SOLAR RADIATION AS A FOREST MANAGEMENT TOOL
a primer and application of principles

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Forests are products of solar radiation use. The sun also drives the hydrologic cycle on forested watersheds. Some basic concepts of climatology and solar radiation are summarized including earth-sun relations, polar tilt, solar energy, terrestrial energy, energy balance, and local energy. An example shows how these principles can be applied in resource management. This paper is designed to be used with an earlier report on controlling solar light and heat in a forest by managing shadow sources.

Retrieval Terms: forest management; solar radiation; hydrologic cycle; climatology; energy exchange.

INTRODUCTION

The sun is the primary source of energy for the earth and its atmosphere. Solar energy drives the biologic, hydrologic, and atmospheric processes. The second largest energy source is the heat flux from the interior of the earth. This second source accounts for only about 0.02 percent of the total. Other sources contribute even smaller quantities of energy.

Our forests are products of solar radiation use. Insolation is used to combine elements found near the surface of the earth so that essential physiological processes necessary for forest growth and maturity can be completed. The sun also drives the hydrologic cycle on our forested watersheds. As land managers, we are interesed in both the forest growth cycle and the hydrologic cycle because wood and water are tangible products of forest land.

We cannot manage or control the incident solar radiation received by large land areas; however, forest management can exert significant effect on local insolation in small areas. Harvest and regeneration patterns can be designed to increase or decrease the radiation level at many sites. The objectives of the management plan can determine the level of insolation desirable. Previously, management of such matters as reproduction and snow water yield considered solar radiation levels broadly or qualitatively before any activity started, but made no specific plan based upon a detailed examination. This paper discusses basic relationships usable to more quantitatively evaluate how solar radiation and shadows can be integrated at specific sites to achieve a management goal.

This paper summarizes some basic concepts of applied climatology and solar radiation. Although the principles are well known to those trained in micrometeorology, they may be less familiar to those working in resource management and planning. An example is included to show how these principles can be used in resource management. The paper is designed to be used with an earlier report *Controlling solar light and heat in a forest by managing shadow sources* (Halverson and Smith 1974a). That report has been supplemented by a series of tables on a tree-shadow length for 2° latitude increments spanning latitudes 30° to 50° N.

Requests for copies of the earlier report—Research Paper PSW-102—and of the shadow-length tables should be directed to: Pacific Southwest Forest and Range Experiment Station, P.O. Box 245, Berkeley, California 94701, Attn: Publications Distribution.

EARTH-SUN RELATIONS

The Sun Affects Our Forests

Several properties of the sun help explain the energy relations of the forest. The sun is our most prominent neighbor in the solar system. In relation to the earth, it is stationary; however, it appears to trace a path across the sky because the earth is rotating on its axis.

The sun, which is at the center of our solar system, has a diameter more than 100 times larger than that of the earth. The sun is 93 million miles (150 million km) from the earth. The solar radiation which reaches the earth arrives in parallel rays because of solar size and distance. If the sun were smaller than the earth, solar radiation would appear as diverging rays. Because the rays are parallel, shadows appear as a direct image of the source projected along the rays to the surface of the earth. Parallelism of solar radiation makes it possible to calculate shadow locations, sun location, and sun times with reasonable accuracy.

Although the sun looks small because of earth-to-sun separation, it contains most of the mass of our solar system, about 99 percent. The sun generates energy through nuclear fusion, creating helium from hydrogen. In the process it converts some mass to energy at a relatively constant rate. The sun should last about another 30 billion years. Much of the nuclear radiation emitted by the sun is screened by distance and atmosphere before it reaches the earth.

The energy emitted from the sun arrives in parallel rays. Because of the fixed and predictable relation of earth to sun one may precisely determine the position and angle at which these rays will strike any portion of the earth on any given day, as well as the energy which arrives at that point unless it has been modified by cloud cover. Arrangements or rearrangement of the spatial distribution of tree boles and crowns can prevent or allow solar radiation reaching any spot of ground. Thus, timber harvest and tree planting can be managed to change the amount of solar radiation reaching the surface. This change in solar radiation amount can be used to increase heat to snowpacks to create melt, to prevent thermal pollution in trout streams, and in other ways.

Polar Tilt Defines Our Seasons

The earth rotates on an axis extending through the polar latitudes and completes one rotation every 24 hours. A variation of about 2 seconds in day length does not significantly affect our purposes. The polar axis tilts 23° 27′ from normal alinement with the plane of the elliptical orbit around the sun and this tilt is responsible for the seasons. Summer occurs when our hemisphere is tipped toward the sun; winter results when we are angled away from the sun.

Our orientation toward or away from the sun is related to the earth's location on an orbit around the sun (*fig. 1*). The earth completes one revolution every 365.25 days, or each year. The sun appears displaced north of the equator during summer and south during winter. The angular displacement is called the solar declination. The points of maximum displacement are referred to as the summer and winter solstice and occur about June 22 and December 22. The vernal and autumnal equinoxes occur about March 22 and September 22 when the earth's orbit crosses the solar equator. The reference plane used to describe the declination of the sun is defined by the earth's equator. As the earth revolves about the sun, the solar disk appears to move below, south of the equator in winter, and above, north of it in summer. The maximum displacement is the same as the tilt of the earth's axis, 23° 27′, and is defined as positive on June 22 and negative on December 22. Latitude is also defined by the same plane through the equator. The tropics—Cancer and Capricorn—are at the same latitude as the maximum declination of the sun; the sun is directly overhead on the appropriate solstice. At the equinox, the sun is in the plane of the earth's equator and declination is zero.

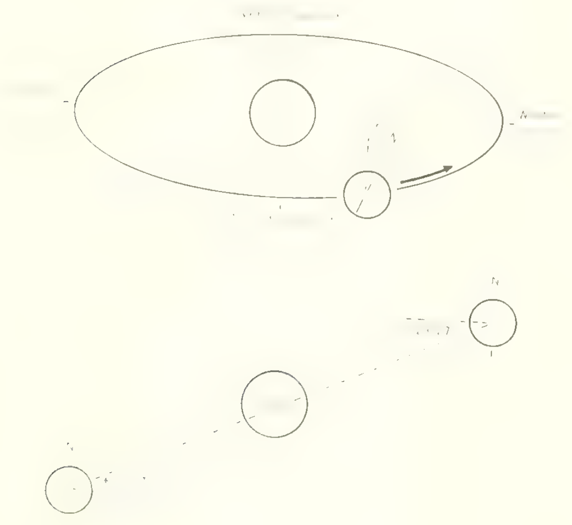

Figure 1. The earth rotates on its axis in an elliptical orbit around the sun. The polar axis tilts 23° 27′ from normal alinement with the plane of the elliptical orbit around the sun.

As the earth progresses through one rotation on its axis every 24 hours, the sun appears to trace a path in the sky and that path completes a circle around the globe each day. This translates to 360° in 24 hours, or 15° per hour. This quantity, 15°, is defined as the *hour angle,* the spherical angle the sun position must traverse per hour so that it will appear in the same place 24 hours hence. It is referenced to noon, true solar time, when the sun is due south of the observer, and is positive before noon and negative after. (It is more precise to say the earth must revolve through an arc of 15° per hour, but manner of presentation does not affect the calculations of sun position.)

The location of the sun in the sky can be described by two angles when the declination, latitude, and hour angle are known. The following equations define the sun *elevation* above the horizontal and the sun *azimuth.* The sun azimuth is the arc of the horizon measured between south and the vertical circle passing through the center of the point of observation and extending to the sun.

Elevation of the sun is given by the equation:

$$\text{sine } e = \sin L \sin d + \cos L \cos d \cos h$$

in which

e = altitude of the sun (angular elevation above the horizon)
L = latitude of the site
d = declination angle of the sun
h = hour angle

The azimuth of the sun is defined as

$$\sin a = \frac{\cos d \sin h}{\cos e}$$

in which a = azimuth of the sun measured eastward (+) or westward (−) from south. The algebraic signs of the two trigonometric functions in the various quadrants are:

Function	*Range in Degrees*			
	0-90	90-180	180-270	270-360
Sine	+	+	−	−
Cosine	+	−	−	+

Another angle frequently encountered in calculation of sun position is the *zenith* angle (Z), the angular separation of the sun from vertical at the site. Therefore,

$$Z = 90° - e$$

and from trigonometric identities

$$\cos Z = \sin e$$

The relationships of the various angles can be diagrammed (*fig. 2*).

These equations give rise to the following facts.

1. At any latitude at solar noon, the hour angle is 0° and $Z = L - d$.
2. The half-day length (H) at all but polar latitudes is $\cos H = \tan L \tan d$. The half-day length will be 6 hours (90°) when tan L is 0—that is to say, all days on the equator. The half-day length will also be 6 hours when tan d equals 0, the equinoxes at all but the polar latitudes.
3. In polar latitudes cos L is 0, sin L is 1, and $\sin a = \sin d$, from the equation for solar elevation. Then the elevation angle of the sun at the poles equals the declination angle.
4. The day is always symmetrical about solar noon on a level surface; that is, sunrise and sunset occur the same number of hours before and after solar noon. The azimuth and elevation angles are the same for equivalent numbers of hours before and after solar noon. Also, the azimuth west of south at sunset is equivalent to the sunrise azimuth east of south. Calculations for the first or second half of a day can be transposed across solar noon to describe the remaining half day.

The calculations described are all based on *true solar time*—sometimes called sun time. Solar time is calculated from solar noon, when the sun is due south, along the meridian, of the observer. Solar time is preferred over standard time because standard time, though based on solar time at the time zone meridians, has been subjected to several modifications. Daylight saving time is now common. Time-zone boundaries

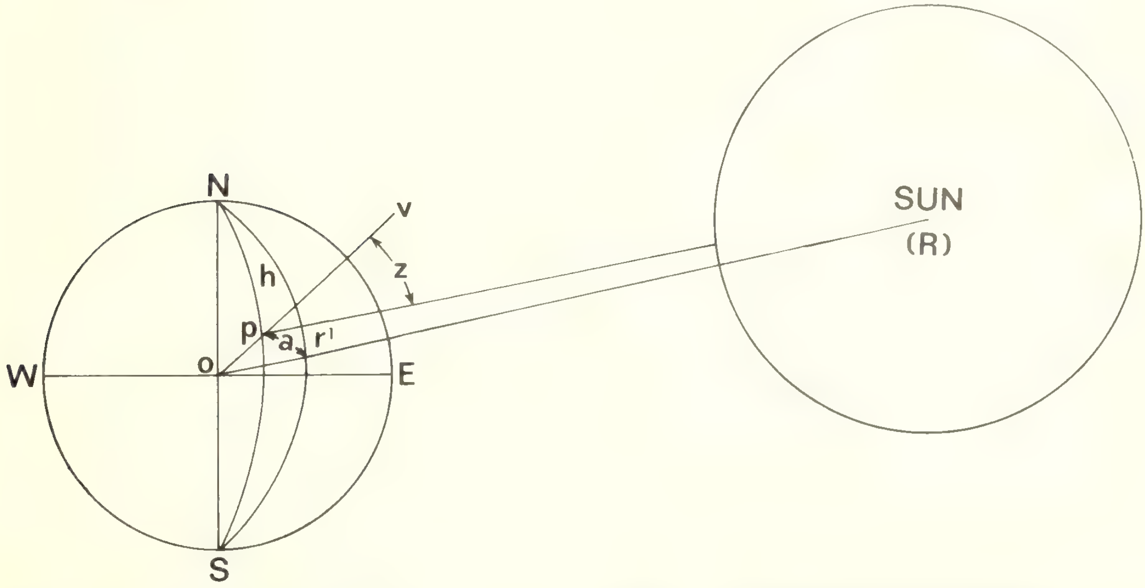

Figure 2. At a given latitude, relationships among the hour angle, zenith angle, and solar elevation can be shown. (R) = the endpoint of a line from the center of the earth (o) to the center of the sun (R), o = center of the earth, p = position of observer, line opv is the vertical at the position of the observer, r′ = line from observer to sun, or ′R = line from the center of the earth to the sun. The various angles are: z = *zenith* angle between center of the sun and the vertical at the position of the observer, h = *hour* angle between NpS and Nr′S, a = *azimuth* of the sun, and 90°-z = *elevation* of the sun.

have been modified also by political entities to place entire States within a single time zone. Local time may vary considerably from solar time in different regions. Using solar time as a base avoids the necessity to consider these variations.

Solar time is referenced to the center of the solar disk. Apparent sunrise occurs slightly before sunrise in true solar time because the edge of the solar hemisphere appears before the center of the sun and because atmospheric refraction makes the solar disk appear slightly earlier. The same two effects also delay sunset. The deviation lasts about 4 minutes at midlatitudes, and increases in time with increasing latitude.

SOLAR ENERGY RELATIONS

The various laws which govern the generation and flux of radiations are well established. These laws, which we apply, date back to the 19th century and earlier, and reached their maturity during "the thirty years that shook physics," from 1900 to 1930.[1] Because these laws are important to the manipulation of solar radiation data for management purposes, they will be reviewed.

The basic unit of energy is the 15° gram-calorie (cal); this is the amount of heat required to raise the temperature of 1 gram of water 1°C. When this energy is expressed on an area basis the unit area is cm^2. The langley (ly) is 1 g calorie cm^{-2}. The kilolangley (kly) is, by convention, 1000 ly. The langley unit is convenient for use in forest science because processes such as evaporation and snowmelt use the calorie as the basic unit. Other disciplines use other units, such as the watt, erg, joule, or British thermal unit (BTU). These quantities are all interchangeable with conversion factors such as

$$\begin{aligned}
\text{One } 15^\circ \text{ g cal cm}^{-2} &= 1 \text{ cal cm}^{-2} \\
&= 1 \text{ ly} \\
1000 \text{ ly} &= 1 \text{ kly} \\
\text{One cal cm}^{-2}\text{min}^{-1} &= 4.1855 \text{ joules cm}^{-2}\text{min}^{-1} \\
&= 4.1855 \times 10^7 \text{ergs cm}^{-2}\text{min}^{-1} \\
&= 69.75 \text{ milliwatts cm}^{-2} \\
&= 3.6855 \text{ BTU ft}^2 \text{ min}^{-1}
\end{aligned}$$

The addition of the time unit, minutes, converts the energy terms to *flux*. Flux is the quantity of radiant energy of all wavelengths (cal) crossing a unit area of surface (cm^2) per unit time (min). Minutes are chosen rather than seconds to prevent negative exponents from appearing with the equivalent energy quantities.

The energy emitted from the sun is about 56×10^{26} ly min^{-1}, and the earth is a mean distance of 1.5×10^{13} cm away from the sun. The energy received per unit area on a sphere with a radius equal to the average distance from the sun to the earth is thus:

$$S = \frac{56 \times 10^{26} \text{ ly min}^{-1}}{4\pi(1.5 \times 10^{13})^2} = 2.0 \text{ ly min}^{-1}$$

in which S is the solar constant.

The solar constant is the energy flux passing through a square centimeter surface normal to the sun's rays per minute. The surface is located at the top of the atmosphere, so that energy actually incident at the ground depends on transmission losses in the atmosphere and the sine of the angle between the earth surface and the rays from the sun. Because of variations in energy output from the sun and differing distances of earth-sun separation, the solar constant varies by about 1.5 percent around the mean value. (Values of the solar constant reported in the literature also vary between 1.94 and 2 ly min^{-1}, but for most purposes, the value 2 ly min^{-1} is acceptable.)

The emission and absorption of radiation by the sun are described by a number of fundamental relations. Different objects emit radiation as a function of their absolute temperature. Kirchhoff (1824-1887) gave us a law which states that the radiating powers of all bodies at a given temperature must be in exactly the same ratio as their absorbing powers, or they could never attain temperature equality. Qualitatively, therefore, Kirchhoff's Law says that good absorbers of energy are also good emitters. A *black body* is an object that emits and absorbs radiation in all wavelengths. The term "black body" is a physical one—it may not describe the color that we see, although generally, objects that appear black to us are also good radiation absorbers and emitters.

If the sun is assumed to be a black body we can calculate its radiation temperature. In 1879, Josef Stefan (1835-1893) deduced that the total emission of a black body for all wavelengths together is proportional to the fourth power of the absolute temperature. Five years later, in 1884, Ludwig Boltzmann proved the law on the basis of thermodynamics. From the Boltzmann experiments we have the Stefan-Boltzmann equation:

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[1] Details of these laws can be gleaned from any basic college-level text on physics should the reader be interested in pursuing the subject for new knowledge, or for review.

$$\text{Flux} = \sigma T^4$$

in which σ is the Stefan-Boltzmann constant (8.14 x 10^{-11} ly min^{-1} T^{-4}).The sun flux is equal to 56 x 10^{26} ly min^{-1} divided by the surface area of the sun (6.093 x 10^{22} cm^2). Solving the equation and extracting the fourth root of the temperature variable yields a radiation temperature of 5800° K.

Black body radiation characteristics were not explained by the wave theory of light. It remained for Max Planck (1858-1947), a theoretical physicist, to determine that all radiant energy comes to us in the form of electromagnetic waves and only in "chunks" or discrete energy packets. These chunks are called *quanta*. Planck, in the early part of this century, discovered that the energy, I, emitted per second per unit area per unit of frequency into a sphere was described by the equation:

$$I = \frac{8\pi h v^3}{C^2 \left[e^{\frac{hv}{\sigma T}} - 1 \right]}$$

in which h is Planck's constant (6.6252 x 10^{-27} erg sec), v is frequency of radiation, and e is the base of the natural log. The Boltzmann constant is expressed in consistent units (1.3805 x 10^{-16} erg deg^{-1}) and C is the speed of light (3 x 10^{10} cm sec^{-1}). To derive the energy emitted in a single direction, Planck's equation is divided by 4π. Planck's law led to modern physics: quantum mechanics and the electromagnetic theory of light.

Planck also assumed that the energy per unit, or quantum of light, is given by the equation:

$$E = hv$$

in which

E = Energy
h = a constant
v = frequency of vibration

This equation can be written also as $E = nhv$, in which *n* is a whole number and is called a *quantum number* and hv is called a *quantum of energy*.

The number of quanta emitted in a large-scale process, such as solar radiation, is so great that individual quanta cannot be distinguished. Such a process, therefore, appears to be continuous. Planck's assumption, later proved correct, gave a method to determine the relative energy of radiation of different frequencies.

Black bodies radiate at several frequencies centered about a maximum. Wilhelm Wien (1864-1928) proved that maximum energy radiated by a hot body shifts to shorter and shorter waves as the temperature rises.

The maximum in terms of frequency can be derived from the relationship

$$v = \frac{C}{\lambda}$$

Using the measured wavelength of maximum radiation we can determine the absolute temperature of an object by solving the equation which approximates Wien's Law. In the general case, Wien's Law is

$$\lambda T = w$$

in which

λ = wavelength
T = absolute temperature
w = Wien's displacement constant

An approximation of Wien's Law, with w determined experimentally is

$$\lambda = 0.2897\ T^{-1}$$

Solving Planck's equation for each frequency is tedious. Using Wien's Law, however, we find that solar radiation is centered about a wavelength near

$$\lambda = 0.2897/5800°\text{K}$$
$$= 0.5 \times 10^{-4}\ \text{cm}$$

Currently, the preferred units for wavelength are *nanometers*. The wavelength of maximum radiation energy is 500 nanometers. About 99 percent of solar radiation is contained in wavelengths defined as shortwave or solar radiation between 150 and 4000 nanometers. Of this, about 9 percent is ultraviolet (150 to 400 nanometers), 45 percent is visible to the human eye (400 to about 740 nanometers), and 46 percent is infrared (740 to 4000 nanometers) (*fig. 3*).

Terrestrial Energy Relations

A little reflection on the nature of Planck's work and Wien's Law tells us that any object whose temperature

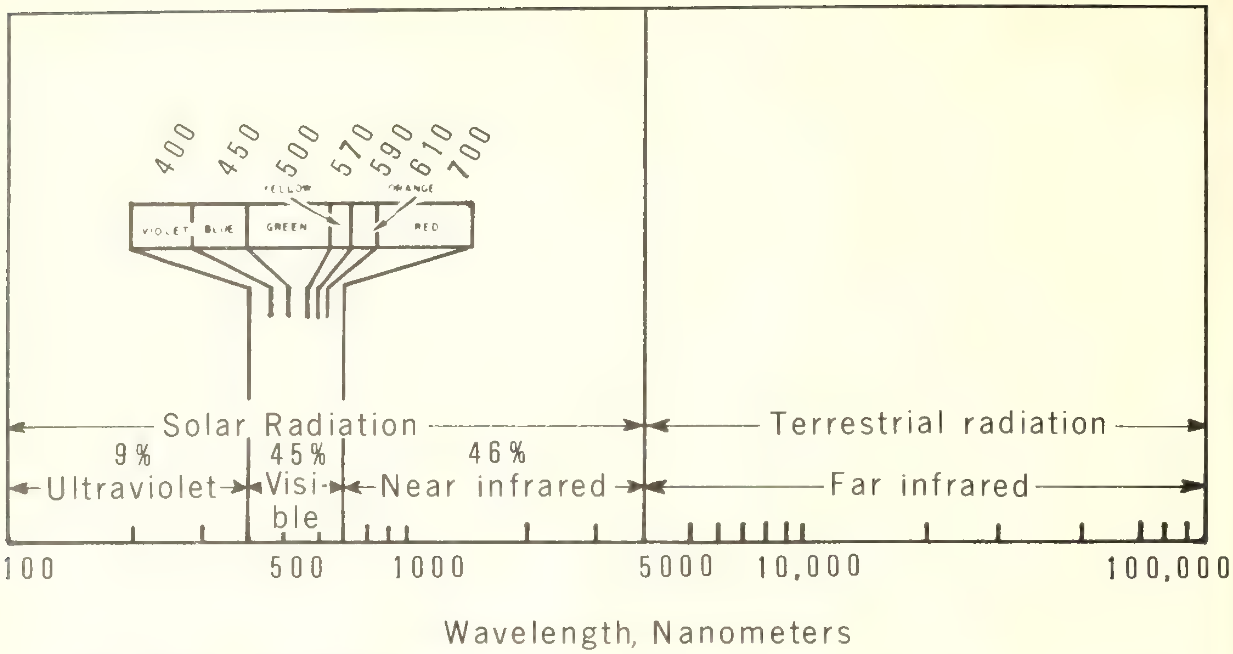


Figure 3. A portion of the electromagnetic spectrum is shown, separated into solar and terrestrial radiation. Visible, ultraviolet, and infrared light waves do not represent all of the known kinds of electromagnetic radiation. Beyond the visible and infrared toward longer wavelengths would be heat waves; beyond the shorter wavelength would be X-rays and gamma rays.

is greater than absolute zero must radiate energy in some wavelength spectrum. This is true for terrestrial objects whose temperature is much below that of solar temperature. If we consider temperatures in the range 273° to 335° Absolute (0°C to 62°C), we find the wavelength of maximum radiation to approximate from 8500 to 11,500 nanometers. These are temperatures we might expect in the forest and at soil surfaces during the year. The wavelengths are not visible, are longer than solar wavelengths and, by convention, are designated longwave or terrestrial radiation (*fig. 3*). Gases like those of the atmosphere emit radiation as well as solid objects and vegetation.

We have treated radiation from sources of various temperatures as discrete quantities, assuming each source is a perfect *black body* which absorbs and emits energy as a function of temperature. A perfect *white body* would absorb and emit nothing and, theoretically, would have a temperature of absolute zero. Most objects fall somewhere in between; that is, they do not absorb all incident energy, emit something less than the flux indicated by the Stefan-Boltzmann Law, and are referred to as *gray bodies*. The ratio of actual to theoretical emission is called *emissivity*. Emissivity is always less than unity. Gray bodies react exactly as black bodies, except that the radiation flux is lowered by a factor equal to emissivity equally in all wavelengths. The term gray body describes radiation properties and not the visible color that we see. If these imperfect absorbers and emitters also function differently at different wavelenghts, that is, if they have a spectral response, they are called *natural* bodies. Spectral responses are usually measured in bands of from 10 to perhaps 100 nanometers. Emissivity is calculated from reflectance and transmissivity of the target in the wavelength band.

Natural bodies reflect some of the energy received. If we speak of a comparatively narrow band or single wavelength, the property is usually termed *reflectivity*. A broader wavelength, such as the entire visible band, shows an integrated reflection called *albedo*. The albedo of new snow in short wavelengths may exceed 90 percent: in other words, only about 10 percent of the solar energy impinging on a snow surface is absorbed.

As solar energy is absorbed, an object warms and emits an increasing flux of longwave energy. One process that occurs naturally is the conversion of solar energy into longwave energy by all the components of the earth-atmosphere system. Since natural bodies are imperfect emitters, the law of conservation of energy implies that some absorbed solar energy is used for another purpose, or transmitted through the body and not emitted. The Stefan-Boltzmann Law can be applied to a gray body when modified by the emittance (ϵ):

$$\text{Flux} = \epsilon \delta T^4$$

The Stefan-Boltzmann Law applies also to natural bodies, but the wavelength or band must be specified as the factor ϵ may vary in different wavelength bands. We usually separate the energy spectrum into short and long wavelengths and use an integrated emissivity.

Snow serves to point out another interesting facet of energy relations. Snow has a high albedo in short wavelengths. However, in the long wavelengths it acts almost as a perfect black body. It absorbs and emits longwave energy close to the theoretical value. The same may hold true for various vegetation types and other natural features of the forest. The example of snow points out the broadband spectral nature that many natural radiation sources exhibit. When discussing energy relations we should specify the wavelength band of interest. Most natural emitters approximate gray bodies over the total longwave spectrum. Soils, vegetation, and snow properties can be approximated with the gray body equations.

ENERGY BALANCE

Of the various energy sources for the earth, the dominant one is the sun. Energy from the sun reaches the earth as shortwave radiation; some is converted to longwave radiation within the earth-atmosphere. Some energy is converted to another form within the biosphere, through chemical reactions or transpiration; some in the atmosphere, through heating; and some within the hydrologic cycle, through snowmelt and evaporation. The energy, however, is eventually released within the earth and atmosphere system because these reactions are all reversible.

Reasonably then, the earth must lose as much energy annually as it receives from the sun. Otherwise the earth and atmosphere would be getting rapidly warmer or colder. But the earth does not get rapidly warmer or colder, at least not permanently, although episodes such as the ice ages indicate there can be geologically short-term alterations.

The earth receives about 263 kly per year at the top of the atmosphere. From there, energy is distributed in the following general proportions. Considering incident shortwave solar radiation first, a reasonable distribution is:

	kly
Solar energy incident at the top of the atmosphere	263
Reflected by clouds	63
Reflected by other atmosphere constituents	15
Reflected from the surface of the earth	16
Total reflection (albedo)	94
Absorbed by clouds	7
Absorbed by other atmospheric constituents	38
Absorbed by the surface of the earth	124
Total absorption	169

One of the processes going on is the conversion of shortwave energy to longwave so that the earth can exist in an energy-balanced state. Therefore, we must lose the equivalent of 169 kly per year in longwave radiation. An approximation of the loss is:

	kly
Longwave radiation emitted by the surface of the earth	258
Lost beyond the atmosphere	20
Absorbed by the atmosphere	238
Longwave radiation emitted by the atmosphere	355
Lost beyond the atmosphere	149
Reabsorbed by the earth's surface	206
Sum of radiation lost from the surface of the earth	52
Sum of radiation lost from the atmosphere	117
Total loss	169

So the earth enjoys an energy balance, emitting as much energy as it receives. This energy is not distributed evenly, however, and varies by geographic location and date (declination). The energy surplus in areas like the tropics is transferred poleward by atmospheric and ocean currents to areas where deficits occur. Each area, then, has a "typical climate." Local climate certainly shows large annual variations—but these are variations about a mean and not simply random total changes in climate.

Although the earth as a whole is in balance, the earth's surface and atmosphere show an energy discrepancy. Examination of annual radiation fluxes shows that the earth's surface absorbs 124 kly per year and radiates 52 kly so the earth's surface gains 72 kly. The atmosphere absorbs 45 kly and radiates 117 kly per year for a negative balance of 72 kly. Energy must be transferred from the ground to the atmosphere. This occurs mainly by absorbing heat through evaporation from the surface and releasing heat by condensation in the atmosphere. Heat transfers upward by convective currents in the air. Air is warmed by conduction when in contact with warm soil and is carried upward by turbulent air movement.

LOCAL ENERGY RELATIONS

Energy fluxes at a single site may not exactly balance during a short time span, one season, for example. Over several years, however, a balance will occur such that energy received and energy lost are equal. The sun is still the primary energy source although horizontal energy transfer by atmospheric motion and ocean currents is necessary to the energy balance over the earth's surface.

Forests can be managed to take advantage of solar energy because the sun provides a predictable flux of energy from a given position. It is difficult, and sometimes impossible, to manage forests to respond to infrequent meteorological events. Solar radiation that reaches the forest is modified in several respects. Atmospheric absorption removes some energy, clouds reflect some back to space, water vapor scatters some and this reaches the earth in a diffuse form, and the incident angle of radiation serves to reduce the flux. At midlatitudes, about half of the solar radiation incident at the top of the atmosphere reaches the surface. This varies considerably depending on atmospheric conditions, elevation, and solar angle at a given site. Predicting incident solar radiation at a site is difficult because of local weather variations, but potential insolation can be estimated (Buffo and others 1972, Frank and Lee 1966).

Some incident shortwave radiation is reflected from the surface on which it falls. The albedos for surfaces we might find are:

Surface:	Albedo *Percent*
Water	6 to 21
Snow	40 to 95
Ice	30 to 40
Soil, dry	20 to 45
Soil, wet	5 to 20
Sand	35 to 45
Desert	25 to 30
Chaparral	15 to 20
Meadow	10 to 20
Forest, deciduous	10 to 20
Forest, coniferous	5 to 15

Longwave radiation is a function of atmospheric and local temperature. The geometry of the sources and sinks at the site also affects the flux of longwave radiation. Any part of the total site can act as a net source or sink of longwave radiation, depending on the effective radiating temperature. The atmosphere above the site also acts as a source or sink for energy in most of the longwave frequency band. Atmospheric components are very poor absorbers of radiation in wavelengths between 8500 and 11,000 nanometers. This "atmospheric window," so named because it is transparent to radiation, allows radiation to escape from the earth-atmosphere system. Thus the atmospheric window in the wavelength band 8500 to 11,000 nanometers shows almost complete transmission of longwave radiation. These are the wavelengths corresponding to radiation at ambient temperatures. About 9 percent of the emitted energy goes directly out of the earth-atmosphere system. Certain atmospheric components absorb longwave radiation in specific radiation wavelengths. The absorbers include water vapor (5300 to 7700 nanometers and beyond 20,000 nanometers), ozone (9400 to 9800 nanometers), carbon dioxide (13,100 to 16,900 nanometers) and clouds (all wavelengths). Absorbed radiation is reradiated in all directions, and some returns to the surface of the earth.

Energy relations at a site depend on the nature of surfaces exposed in long as well as short wavelengths. The emissivity and absorptivity of some terrestrial radiation sources are approximately:

Source:	Emissivity *Percent*
Water	92 to 96
Snow	89 to 99.5
Ice	96
Soil, wet	95 to 98
Soil, dry	90
Sand	89 to 95
Desert	90 to 91
Meadow	90
Forest, deciduous	90
Forest, coniferous	90

Albedo and emissivity will vary; therefore the tabulated values above are in the range that may be expected. Albedo increases as the incident angle of radiation decreases. The values for albedo assume the sun is near zenith, so albedos in early morning and late afternoon would be higher. Emissivity does not vary as much because it is a property of the radiating body. Emissivity, however, may vary slightly with temperature. The emissivity variance is so slight for a given natural body that it is usually ignored, except when working with narrow wavelength bands.

If we use the basic information about the sun and the radiation properties of the various surfaces in the forest, we can draw some general conclusions.

Direct solar radiation is the best variable to manage because solar location and flux are predictable. Diffused solar radiation is scattered downward from all parts of the sky and vegetation management would have small effect.

Longwave radiation fluxes occur when parts of the site absorb direct insolation. We can exert some control over longwave radiation levels by controlling the parts of a site which are exposed to solar radiation. In general, a site exposed to solar radiation shows secondary effects including increased soil temperature, maximum air temperature, evaporation, and transpiration. Heat fluxes are greatest at the ground surface, but maximum temperatures will be attained in air immediately above the ground which is receiving radiation from both the atmosphere and the ground. If streams or snow are present, the water temperature will rise, or snowmelt will be faster in the spring.

Radiation flux into the site will be greatest during midday because albedo is lowest when the sun is near zenith. Forest components are not theoretical gray bodies but have a spectral response. Soils and growing vegetation, however, absorb radiation in almost all wavelengths so they warm rapidly and emit large fluxes of longwave radiation when exposed to the sun. Snow and water are reflective in the shortwave portion of the spectrum, but are nearly perfect absorbers and emitters of longwave radiation.

MANAGEMENT TECHNIQUES

Solar radiation adds some 263 kly of energy to the earth and atmosphere each year. Although this energy is reflected or eventually emitted by the earth, some is retained and used to drive the various physiological and biological processes with which we are familiar.

The value of total incident radiation does not tell us much about the level of energy at forest sites. Tables of solar beam irradiation are available for the mid-latitudes, however. The tables published by Frank and Lee (1966) list the potential solar radiation levels for various aspects at several different dates. If we consider a level site at 40°N latitude as an example, the potential solar radiation ranges from a low of 328.9 to a high of 1022.7 ly per day. Assuming 50 percent atmospheric attenuation, the soil, snow, or vegetation receives 164.4 to 511.4 ly per day of direct beam solar radiation. If all this energy were absorbed it could, each day, melt from 2 to 6.5 cm of ice, evaporate approximately 0.3 to 0.8 cm of water, or raise the temperature of 100-cm depth of water from 1.6° to 5.1°C. Although some of this energy is converted to longwave at the site, it is all incident, and must be lost from the site in some manner. Longwave emittance, evaporation, and air movement all help dissipate the energy.

Shortwave radiation may arise from direct beam insolation or it may be reflected into a site by clouds, snow-covered slopes, or other objects. Incident shortwave radiation may exceed expected levels if additional reflected energy supplements direct solar radiation. In one case, measurements of incident shortwave radiation on a tree stem showed the highest radiation level at the north side. The source was reflected energy from a snow-covered south aspect located north of the tree.

Longwave radiation plays other important roles in forest site-energy relations. Most parts of a forest absorb longwave radiation better than shortwave; consequently, heat from longwave radiation remains within a site longer than energy from shortwave. Shielding the site from shortwave energy also lowers the longwave radiation level. Shading should include not only the soil or snow surface but also the trunks of boundary trees. Tree trunks emit high levels of longwave radiation after exposure to the sun. The snow can be shaded from both longwave and shortwave radiation by using tree shadows to shield tree trunks and the snow from direct and reradiated energy.

Managing a site to utilize tree shadows requires some new considerations. Various site conditions, such as bordering mountains, slope, aspect, latitude, and solar declination must be considered. These factors are not subject to any management scheme. Forest vegetation, however, *is* subject to management and shadows are the best tool we have to affect direct solar radiation and emitted longwave radiation. In developing management plans we have to consider both the fixed factors and those subject to management. The desired result may be reached by maintaining minimum solar exposure or by exposing an area to both direct and reradiated energy. Minimum exposure, for example, would result in lower soil temperature, delayed snowmelt, lower stream temperatures, reduced evapotranspiration, and reduced levels of other energy-dependent processes.

There are situations where maximizing solar exposure is desirable. These include clearing snow from roads or buildings, warming campsites earlier in the season, and generally increased rates of energy-dependent processes, such as organic matter oxidation.

Encouraging reproduction is a special case, with the silvicultural requirements of the desired species setting the solar energy requirements.

Modern forestry is based on a multiple-use concept. In each area we must balance our management of energy in the forest to accommodate all the uses of the land. Evaluating all variables and developing the final management plan is still the responsibility of the land manager. The management objectives determine how shadows should be used. Management plans might also indicate that only certain seasons of the year are important. For example, snowmelt occurs at the greatest rate in late spring. April and May might be considered critical and a goal of delaying snowmelt and runoff can be reached by shading the snow surface and the boles of trees surrounding small openings or strips.

Developing a set of shadow length calculations for each application would be tedious. In some situations a specific table for an area might be necessary. A computer program that completes all the necessary calculations is available (Halverson and Smith 1974a). Input data include latitude, date, east and south slope components, and the time interval needed between shadow calculations. Output information includes total, north and west shadow extent, and the sun azimuth for each time interval after sunrise.

For more general applications, tables are available for alternate latitudes between 36° and 50°N (Halverson and Smith 1974b). Seven dates between the longest and shortest day are included. Slopes are varied in both north-south and east-west dimensions to a maximum of 40°. Selection of the proper table includes determining the site latitude, dates of interest, and the slope and aspect measured in cardinal directions. Tabulated information includes the shadow vectors in cardinal directions, and the shadow length and sun azimuth for each hour after sunrise. Interpolation for intermediate latitudes, slopes, or dates will give acceptable results.

EXAMPLE: A MANAGEMENT PROBLEM

A land manager wants to harvest part of an old-growth red fir stand on a 5 to 15 percent north-facing slope at latitude 40°N at 7000-feet elevation in the Sierra Nevada of California. His objective is to delay snowmelt as late in the season as possible for late season streamflow increase, and to delay onset of the summer soils drought for increased seedling survival. He has determined that a strip-cut form of harvest in which strips would be clearcut in widths of 132 feet would be silviculturally desirable. He now must determine the optimum direction for strip orientation to achieve his objective.

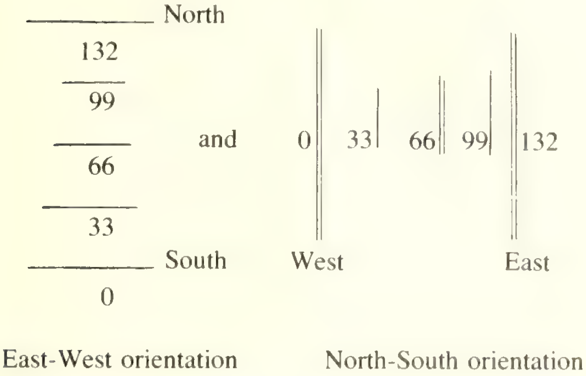
Drawing from an example used in our earlier publication (Halverson and Smith 1974a), let us assume we are interested in the distribution of energy across two long, narrow openings which are usually covered with snow in the winter. But we also need to know the energy distribution during the day and at several points in the opening.

Let us assume:

1. Latitude 40°N
2. The openings are 2 chains wide (132 feet), one is oriented N-S, the other E-W
3. The slope is 9°N
4. The date of interest is April 1
5. Border trees are 100 feet tall

We assemble some necessary information: The shadow table is available in an earlier publication (Halverson and Smith 1974b). But we need information on potential solar radiation. The tables by Frank and Lee (1966) list only *daily totals* and will not give us *distribution during the day*. Diagrams by Buffo and others (1972), however, give hourly radiation fluxes for a variety of dates and slopes, so we decide to use these tables. As often happens, the solar radiation tables do not list the exact date and slope of interest. And Buffo and others (1972) assumed an atmospheric transmission of 0.9. Transmission of solar radiation through the atmosphere varies because of changing cloud cover, turbidity, and atmospheric thickness above the site (determined by site elevation). At mid-latitudes, atmospheric transmission usually varies from about 0.5 to 0.9, with an average near 0.6. An atmospheric transmission of 0.9 might not be applicable for our purposes because of unusual local conditions, such as air pollution. Local meteorologists will be able to supply an estimate of atmospheric transmission. Difficulties are often encountered because of the extensive range of slopes and numerous dates for which transmission coefficients would yield an almost infinite number of combinations. If the site is very critical, corrections would be required. But for most purposes we can accept some approximations. We will assume:

1. Use the solar radiation isogram for March 21 (Buffo and others 1972).
2. Divide the openings by half chain intervals as shown in the following drawing.



3. Use 1-hour intervals, starting at 05.78 hours, sunrise, to 17.78 hours, just before sunset.
4. A—in the data column indicates the point is in the shade, and 100 percent of the solar beam irradiation was intercepted by the border vegetation.

The calculations done hourly from sunrise to sunset would yield an insolation profile *(table 1)*.

We can check our calculations by noting that radiation total at a point exposed all day, about 540 ly, falls within the range given by Buffo and others (1972) which is 564 for a slope of 0 and 420 for a slope of 15 percent. Also, we need to note the uneven radiation distribution evident in the opening oriented east and west.

Table 1. Hourly insolation profile (ly hr^{-1}) for March 21 across a 132 foot wide clearcut strip at 39.5° N latitude

Time	East-West Orientation					North South Orientation				
	0	33	66	99	132	0	33	66	99	132
05.78	-									
06.78			10	10	10					
07.78		-	-	30	30					
08.78		-	-	50	50					
09.78			--	60	60	60	60			
10.78		-	-	77	77	77	77	77		
11.78	-			77	77	77	77	77	77	
12.78				77	77		77	77	77	77
13.78	--			60	60			60	60	60
14.78			-	50	50					50
15.78			--	30	30			-		
16.78			-	20	20					--
17.78	5	5	5	5			-			
Total	5	5	15	546	541	214	291	291	214	187

It is evident that from about 9 a.m. to about 4 p.m., the north wall of timber and the last 35+ feet of snow in the east-west cut strips were subjected to large amounts of solar radiation. The north wall of timber heated up from this constant radiation would, in turn, radiate heat to the pack.

In the north-south oriented strip, the snow across the strip was subjected to direct radiation only for a 3 to 4 hour period at any point rather than for the entire day, as shown in the east-west strip situation.

The snowmelt pattern which resulted was such that, on May 4, 1966 when only 2 area inches of water were left in the snowpack next to the south wall of timber in the east-west strips, there was a complete cover of snow over the north-south strip. It contained 10 inches of water *(figs. 4 and 5)*.

Conifer seed germination and seedling survival were abundant and uniformly distributed across the north-south oriented strips. The abundant number of seedlings found near the south side of the east-west oriented strips decreased significantly in direct relation to nearness to the north wall of timber.

Number of seedlings surviving the dry summer on this transect were in direct relation to the length of time snow remained on the soil. Snow disappeared early enough along the north wall of the east-west strip so that low, night air temperatures caused freezing of the exposed soil and the seedlings frost-heaved. Because the soil in this area was subjected to more heat, it dried out earlier and the seedlings were desiccated. A successful seedling crop was established only after a spring in which massive winter snows did not melt until mid-June. At this time danger of frost-heave had ceased, the summer drought was short enough to prevent massive early season desiccation of the soil, and the more vertical sun did not heat up the north wall of timber to the extent possible in April and May.

Although this illustration relates to soil moisture and seedling survival, one may control solar radiation with shadows, or their lack, for many purposes. Stream temperatures may be ameliorated, snow covered campgrounds opened up sooner, snow covered roads may be opened sooner or kept closed longer, and many other goals may be achieved by using the sun's energy both as direct radiation and as absorbed and reradiated heat.

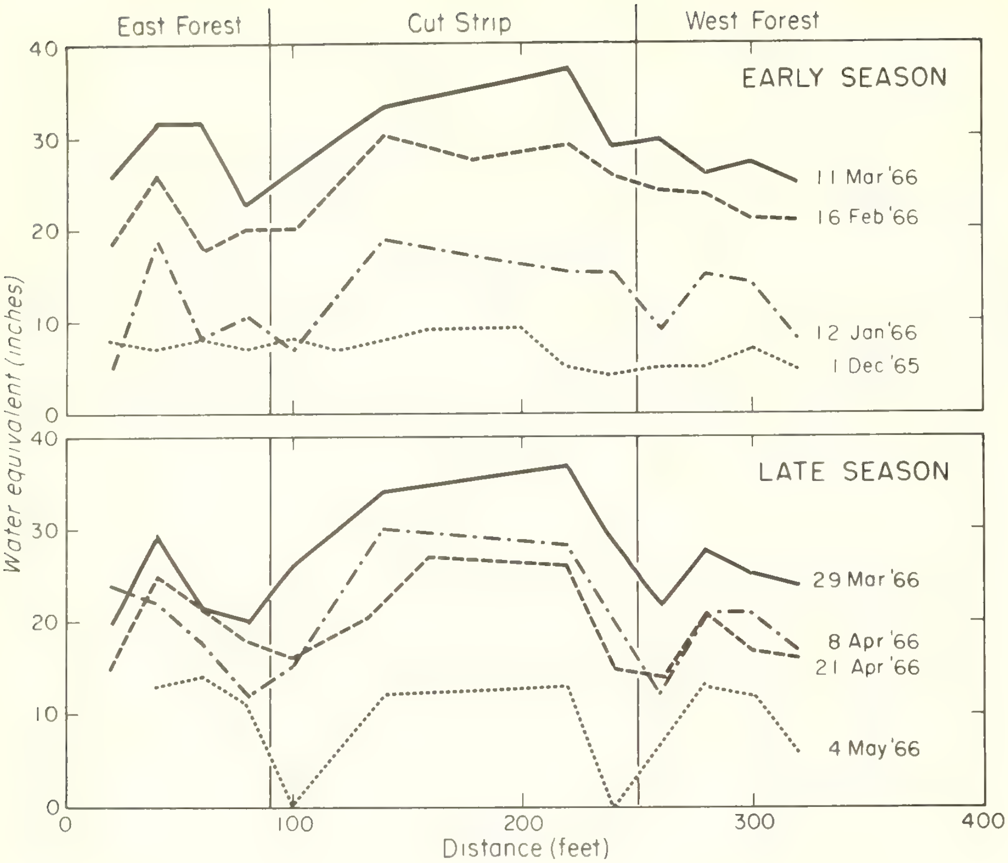
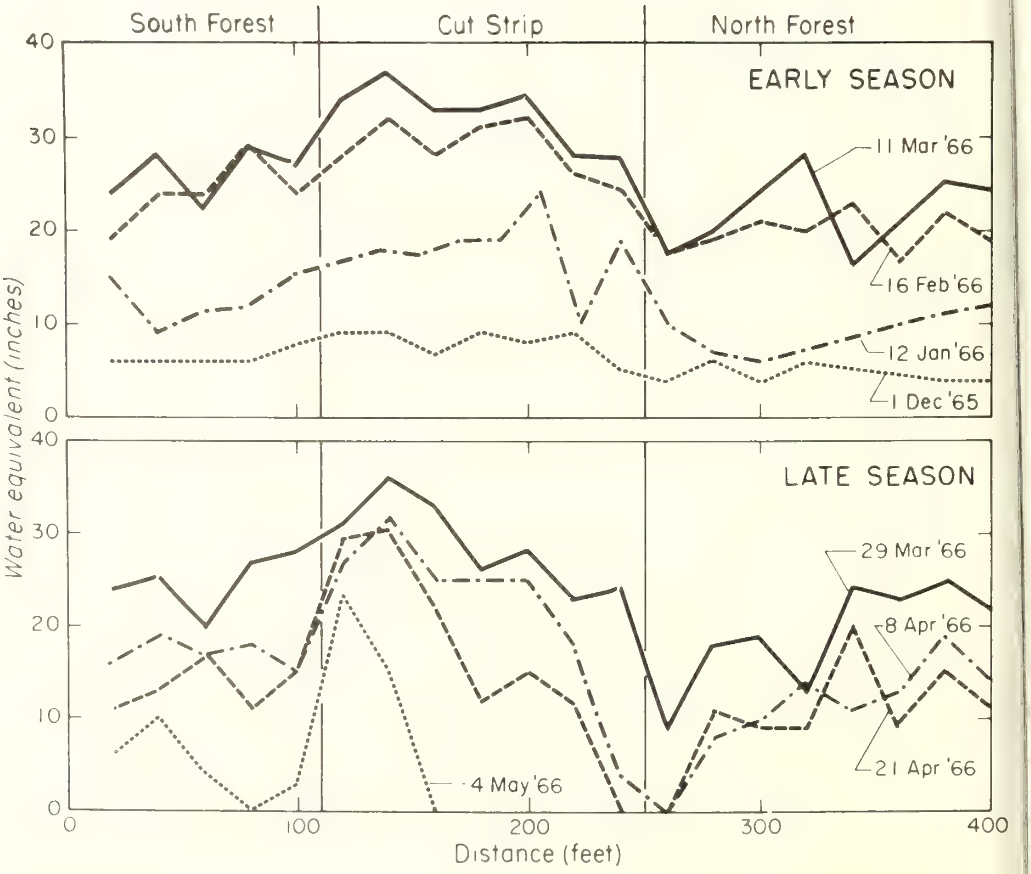


Figure 4. Water content of the snowpack varied by location across a 166-foot wide east-west oriented clearcut strip and in the adjacent forest to north and south.

Figure 5. Water content and location of the snowpack across a 166-foot wide north-south oriented clearcut strip and in the adjacent forest to the east and west.



LITERATURE CITED

Buffo, John, Leo J. Fritschen, and James L. Murphy.
1972. **Direct solar radiation on various slopes from 0 to 60 degrees north latitude.** USDA Forest Serv. Res. Paper PNW-142, 74 p. Pacific Northwest Forest and Range Exp. Stn., Portland, Oreg.

Frank, Ernest C., and Richard Lee.
1966. **Potential solar beam irradiation on slopes.** USDA Forest Serv. Res. Paper RM-18, 116 p. Rocky Mountain Forest and Range Exp. Stn., Fort Collins, Colo.

Halverson, Howard G., and James L. Smith.
1974. **Controlling solar light and heat in a forest by managing shadow sources.** USDA Forest Serv. Res. Paper PSW-102, 1974, 14 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Halverson, Howard G., and James L. Smith.
1974a. **Shadow length tables for latitude 36° north.** USDA Forest Serv., 49 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Halverson, Howard G., and James L. Smith.
1974b. **Shadow length tables for latitude 38° north.** USDA Forest Serv., 49 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Halverson, Howard G., and James L. Smith.
1974c. **Shadow length tables for latitude 40° north.** USDA Forest Serv., 49 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif

Halverson, Howard G., and James L. Smith.
1974d. **Shadow length tables for latitude 42° north.** USDA Forest Serv., 49 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Halverson, Howard G., and James L. Smith.
1974e. **Shadow length tables for latitude 44° north.** USDA Forest Serv., 49 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Halverson, Howard G., and James L. Smith
1974f. **Shadow length tables for latitude 46° north.** USDA Forest Serv., 49 p. Pacific Southwest Forest and Range Exp Stn., Berkeley, Calif.

Halverson, Howard G., and James L. Smith
1974g. **Shadow length tables for latitude 48° north.** USDA Forest Serv., 49 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Halverson, Howard G., and James L. Smith
1974h. **Shadow length tables for latitude 50° north.** USDA Forest Serv., 49 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

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Evans, Peter A., compiler.
1979. **Directory of selected forestry-related bibliographic data bases.** Gen. Tech. Rep. PSW-34, 42 p. Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., Berkeley, Calif.

This compilation lists 117 bibliographic data bases maintained by scientists of the Forest Service, U.S. Department of Agriculture. For each data base, the following information is provided: name of the data base; originator; date started; coverage by subject, geographic area, and size of collection; base format; retrieval format; ways to query; who to query, and availability. Four indexes are included: subject, originator, geographic coverage, and Forest Service and other locations.

Retrieval Terms: Information systems, bibliography, directories, forests, forestry.

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Directory of Selected Forestry-related Bibliographic Data Bases

Peter A. Evans, compiler

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Pacific Southwest Forest and Range Experiment Station
P.O. Box 245
Berkeley, California 94701
September 1979

A data base is an organized collection of information. Generally, for the ease of updating and maintenance, the information is recorded on cards, microfiche, or computer tape. Usually one or more indexes (author, title, subject, etc.) are provided to allow a planned rather than a random approach to the information. FORESTRY ABSTRACTS, both the printed version prepared by Commonwealth Forestry Bureau and the computer service supplied by Lockheed, is a data base; so is the card catalog in a library.

This directory provides access to 117 data bases maintained by scientists of the Forest Service, U.S. Department of Agriculture. It is a selection, not a complete listing, of these data bases. Most of them are bibliographic, although a few provide raw data (usually resource inventories) or names and addresses.

Many of these data bases were begun and are maintained by an individual because of his or her personal interest within the field of forestry or a related discipline. All material listed appears with permission of the person who will respond to inquiries, but this response will often be in addition to that person's normal duties. Rarely is maintenance of the data base, or assistance in its use, a required part of the person's job. Therefore, users should respect limitations on the form, time and place of response.

Although this directory is not a complete listing of Forest Service data bases and despite the obvious limitation of all directories—they are quickly out of date—this publication should make it easier for foresters, land managers, researchers and others interested in natural resources to exchange information.

HOW TO USE THE DIRECTORY

For each of the 117 entries, this directory provides the following:

- Name of the data base.
- Who started it (originator).
- When it was started.
- Data base coverage by (a) subject, (b) geographical area, and (c) size of collection.
- Manner in which the originator organized the information (Base format).
- Manner in which you will receive an answer to your inquiry (Retr. format) and an estimate of the time it will take you to get an answer.
- Way in which you should ask your question (Retr. element).
- Who to ask (Contact).
- Who may use this service (Availability) and whether it is free or a charge is imposed.

The data bases are arranged in alphabetical order, by title. For each data base there is an accession number, which is used to index it in four ways: subject, originator, geographical coverage, and Forest Service experiment station or laboratory at which located.

A sample entry is provided below:

Accession number

Title

Originator

Date started

1 ADHESIVES/Bryan River/1966

Coverage:	Adhesives, buildings, wood	*Keyword description*
	Worldwide	*Geographical coverage*
	Index from 1966 includes hard copies in personal file, dealing mainly with adhesives but also with the use of adhesives and wood in building construction. There is also a listing of laboratory reports on adhesives since 1910.	*Abstract*
	1400 citations	*Approximate number of citations (as of June 1978)*
	100 citations per year	*Approximate number of citations added per year*
Base format:	Author and title references	*Type of information available*
Retr. format:	Computer printout/2 weeks System used: KWIC index Computer center: Univ. of Wis. Madison Area Comput. Cent.	*Form in which you will receive answer to inquiry/estimated time it should take to get answer* *When computer printout is involved, the system and source are given*
Retr. element:	Title only, *or* keywords	*Information you must supply to receive an answer*
Contact:	Bryan River Forest Products Laboratory P.O. Box 5130 Madison, WI 53705 (608) 257-2211 FTS (8) 364-2403	*Name, address, and telephone number(s) of person to contact*
Availability:	Forest Service, faculty, graduate students and anyone who wishes to come to FPL and use the data base on the site/free.	*Who may have access to data base* *Charges, if any, for service*

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DATA BASES

1 **ADHESIVES/** Bryan River / 1966

Coverage: Adhesives, buildings, wood

Worldwide

Index from 1966 includes hard copies in personal file, dealing mainly with adhesives but also with the use of adhesives and wood in building construction. There is also a listing of laboratory reports on adhesives since 1910.

1400 citations

100 citations per year

Base format: Author and title references

Retr. format: Computer printout/ 2 weeks
System used: KWIC index
Computer center: Univ. of Wis.--Madison Area Comput. Cent.

Retr. element: Title only, *or* keywords

Contact: Bryan River
Forest Products Laboratory
P.O. Box 5130
Madison, WI 53705
(608) 257-2211
FTS (8) 364-2403

Availability: Forest Service, faculty, graduate students, and anyone who wishes to come to FPL and use the data base on the site/ free

2 **AIR POLLUTANT EFFECTS ON FORESTS/**
Paul R. Miller / 1965

Coverage: Pollutants, species, effects, physiology, ecosystems, meteorology

Worldwide

Reprint library organized according to FAMULUS specifications, many keywords. Includes information on forest ornamental and crop plants and air pollution effects.

867 citations

50 to 60 citations per year

Base format: Bibliographic citation, keywords, reprints, a few translations

Retr. format: Computer printout, letter *or* verbal--by telephone or in person at site of data base.

System used: FAMULUS

Computer center: Univ. Calif. Riverside Comput. Cent.
Compatible with: IBM 360/50

Retr. element: Author and title

Contact: Paul R. Miller
Pacific Southwest Forest and Range Exp. St.
Universty of California
Riverside, CA 92521
(714) 787-3661
FTS (8) 796-1474

Availability: Forest Service, faculty, graduate students, and others/ free, but unable to handle a large volume of requests.

3 **ALLELOPATHY/** Stephen B. Horsley / 1973

Coverage: Allelopathy, allelochemicals, competition

Worldwide

Articles on the phenomenon of allelopathy, the biochemicals producing inhibition, methods of isolation and identification, physiological and ecological effects of the allelochemicals.

1000 citations

100 citations per year

Base format: Bibliographic citations, keywords, reprints

Retr. format: Photocopy or letter/ 1 week; *or* verbal--by telephone or in person at site of data base

Retr. element: Author and title, *or* summary of information needed

Contact: Stephen B. Horsley
Northeastern Forest Exp. St.
P.O. Box 928
Warren,PA 16365
(814) 563-7587
FTS (8) 722-3311

Availability: Forest Service, faculty, graduate students, and others/ free

4 **ARMILLARIA ROOT ROT/** Charles G. Shaw,III / 1970

Coverage: Epidemiology, ecology, pathogenicity, control, taxonomy

Worldwide

Forestry oriented, but contains control and taxonomy references to horticulture; information on the serious and worldwide diseases of forest trees in both natural forests and plantations.

1000 citations

30 to 50 citations per year

Base format: Bibliographic citations, keywords, abstracts, translations

Retr. format: Photocopy or letter/ 2 weeks; *or* verbal--in person at site of data base

Retr. element: Author only, *or* title only

Contact:
Charles G. Shaw, III
Pacific Northwest Forest and Range Exp. St.
P.O. Box 909
Juneau, AK 99801
(907) 586-7301
FTS (8) 399-0150

Availability: Forest Service, faculty, graduate students, and others/ free, postage for large orders

5 **ASPEN-INTERMOUNTAIN WEST/** Roy Harniss / 1978

Coverage: Ecology, physiology, management, modeling

North America

1000 citations

75 citations per year

Base format: Bibliographic citations, keywords

Retr. format:
Computer printout/ 2 weeks
System used: FAMULUS
Computer center: Washington State University Computer Center
Compatible with: AMDAHL (IBM 360)

Retr. element: Author only, *or* author and title

Contact:
Elizabeth Close or Roy Harniss
Intermountain Forest and Range Exp. St.
507 25th Street
Ogden, UT 84401
(801) 399-3370 or 752-1311
FTS (8) 586-3370 or 3270

Availability: Forest Service/ free

6 **BACKCOUNTRY PROGRAM-DURHAM LABORATORY/** Raymond Leonard / 1973

Coverage: Recreation management, composting sewage, wilderness, planning

North America

Subjects include backcountry facilities, remote forest resources, recreation management approaches, sociological research on backcountry and wilderness users and composting/ sewage research papers.

2200 citations

100 citations per year

Base format: Author and title references, bibliographic citations

Retr. format: Letter/ 2 weeks; *or* verbal--by telephone

Retr. element: Author only, *or* keywords

Contact:
Raymond Leonard
Northeastern Forest Exp. St.
Concord-Mast Road
P.O. Box 640
Durham, NH 03824
(603) 868-5576 or 9697
FTS (8) 834-0797 or 0798

Availability: Forest Service, faculty, graduate students, and others/ free

7 **BIBLIOGRAPHY--FOREST LAND OWNER STUDIES/** Eugene M. Carpenter / 1977

Coverage: Absentee ownership, forest ownership, small and private ownership, nonindustrial ownership, forest practices

Worldwide

Contains abstracts of small, private, nonindustrial forest and woodland ownership studies documenting owner characteristics, behavior toward forest management and management incentive programs, ownership patterns and trends, marketing and economic problems, taxation, impact on wood supply and related subjects.

425 citations

[No record or history of citations added per year]

Base format: Bibliographic citations, abstracts

Retr. format: Letter/ 1 week

Retr. element: Keywords, *or* author and title

Contact:
Project Leader
North Central Forest Exp. St.
2215 East 5th Street
Duluth, MN 55812
(218) 724-1046
FTS (8) 783-9314

Availability: Forest Service, faculty, graduate students, and others/ free

8 BIOLOGICAL EFFECTS OF AIR POLLUTANTS ON PLANTS, ANIMALS AND MICROORGANISMS/ U.S. Environmental Protection Agency / 1950

Coverage: Air pollution, trees, effects (growth, yield, symptoms), pollutant- pathogen interactions

Worldwide

Oriented toward biological effects of air pollutants (including heavy metals) on the terrestrial ecosystem. Includes articles on heavy metals-aerial and root absorption by plants. Excludes articles dealing with pesticides.

15000 citations

2500 citations per year

Base format: Bibliographic citations, keywords, reprints, translations

Retr. format: Photocopy or microform/ 1 week

Retr. element: Summary of information needed

Contact:
Clyde R. Bogle
W.J. Kerr Library
Oregon State University
Corvallis, OR 97331
(503) 754-2840

Availability: Forest Service, faculty, graduate students, and others/ reproduction costs plus postage

9 BIOLOGY AND CONTROL OF *ATTA*/ John C. Moser / 1958

Coverage: Leafcutting ants, ant, *Atta*

Western Hemisphere

Biology, ecology, and control of leafcutting ants (*Atta*). Primary emphasis is on the town ant, *Atta exana* (Buckley), also some coverage of fungus-growing ant tribe (*Attini*).

1000 citations

50 citations per year

Base format: Author and title references

Retr. format: Letter/ 1 week; *or* verbal--by telephone

Retr. element: Author and title

Contact:
John C. Moser
Southern Forest Exp. St.
2500 Shreveport Highway
Pineville, LA 71360
(318) 445-6511 (ext.) 358
FTS (8) 497-3358

Availability: Forest Service, faculty, graduate students, and anyone interested/ free

10 BOREAL PLANT ECOLOGY/ Leslie A. Viereck / 1973

Coverage: Fire effects, taiga, vegetation types, ecology

Circumboreal

Contains a wide range of entries, special interest in tundra and taiga ecology, especially in fire effects, permafrost, vegetation classification, nutrient cycles, and plant succession.

1000 citations

100 citations per year

Base format: Author and title references, bibliographic citations, keywords, abstracts

Retr. format: Computer printout/ 2 weeks
System used: FAMULUS
Computer center: Univ. of Alaska Comput. Cent.
Compatible with: Honeywell H.I.S. 66/20

Retr. element: Keywords (personal index for keywords is available)

Contact: Leslie A. Viereck
Pacific Northwest Forest and Range Exp. St.
Fairbanks, AK 99701
(907) 479-7313
FTS (8) 399-0150

Availability: Forest Service/ computer costs

11 **BREEDING NUT PRODUCING SPECIES: JUGLANS AND CARYA/** David Funk / 1965

Coverage: Genetics, walnut, hickory, pecan

Worldwide

Includes references dealing with biochemistry, morphology, phenology, physiology, flowering, seed orchards, propagation, nursery practice, and plantation culture.

800 citations

25 citations per year

Base format: Bibliographic citations, keywords, abstracts

Retr. format: Photocopy / 1 week (A complete file of 790 references , published by IUFRO Working Party S2.03.06, with subject index, is available for $20 copy charge.)

Retr. element: Author only, *or* title only, *or* author and title, *or* summary of information needed

Contact: Martha K. Dillow
North Central Forest Exp. St.
Southern Illinois University
Carbondale, IL 62901
(618) 453-2318
FTS (8) 955-4200

Availability: Forest Service, faculty, graduate students/ reproduction costs plus postage

12 **CAMPING MARKET SURVEYS/** Wilbur F. LaPage / 1970

Coverage: Camping Market Surveys

North America

Includes nearly 300 copies of published and unpublished surveys and observational surveys of campers conducted between 1936 and 1973. The majority are American and Canadian. Surveys are organized into five categories: national, regional, local, readership, and miscellaneous.

280 citations

10 citations per year

Base format: Author and title references, bibliographic citations, annotations, reprints

Retr. format: Photocopy or letter/ 2 weeks; *or* verbal--by telephone or in person at site of data base

Retr. element: Author and title

Contact: Wilbur LaPage
Northeastern Forest Exp. St.
P.O. Box 640
Durham, NH 03824
(603) 868-5576
FTS (8) 834-0797 or 0798

Availability: Forest Service, faculty/ free

13 **CATALOG OF VIRAL DISEASES OF INSECTS (IVC)/** Mauro E. Martignoni / 1960

Coverage: Insect diseases, insect pathology, insect viruses

Worldwide

IIVCR is a rigorously structured worldwide catalog of the literature on viral diseases of insects and mites. The catalog contains names of host species, genera, and families; names of viral diseases (viruses pathogenic for insects and mites); and subject matter keywords.

3150 citations

400 citations per year

Base format: Bibliographic citations, host species, genus, family, name of viral disease, subject areas

Retr. format: Computer printout, photocopy or letter/ 2 weeks
System used: FAMULUS
Computer center: Bonneville Power Adm., Portland
Compatible with: CDC 6500

Contact: Mauro E. Martignoni
Pacific Northwest Forest and Range Exp. St.
3200 Jefferson Way
Corvallis, OR 97331
(503) 757-4328
FTS (8) 420-4328

Availability: Forest Service, faculty, graduate students in insect virology/ reproduction costs plus postage

14 CHRISTMAS TREES/ Jean W. Nolley / 1930

Coverage: Production management, business management, silviculture, marketing

North America

Comprehensive bibliography dealing with all phases of the Christmas tree business. Emphasis on production and marketing.

1500 citations

80 to 100 citations per year

Base format: Bibliographic citations, keywords

Retr. format: Photocopy or computer printout/2 weeks
System used: FAMULUS
Computer center: Virginia Polytech. Inst. and State Univ., Blacksburg
Compatible with: IBM 370

Retr. element: Author and title *or* keywords

Contact:
Jean W. Nolley
Northeastern Forest Exp. St.
P.O. Box 152
Princeton, WV 24740
(304) 425-8106
FTS (8) 924-4553

Availability: Forest Service, faculty, graduate students, and Christmas tree growers/ free

15 CONE AND SEED INSECTS/ E.P. Merkel / 1956

Coverage: Insects, cones, seeds, seed orchards, conifers

North America

Contains identification, impact evaluation, biology and control of insects destructive to flowers, cones, and seeds of North American coniferous trees.

800 citations

10 to 20 citations per year

Base format: Author and title references, bibliographic citations

Retr. format: Photocopy / 1 month

Retr. element: Bibliographic citations

Contact:
Edward P. Merkel
Southeastern Forest Exp. St.
P.O. Box 70
Olustee, FL 32072
(904) 752-0331
FTS (8) 946-2846

Availability: Forest Service, faculty, graduate students/ free

16 *CRONARTIUM RIBICOLA*/ Ray Hoff / 1969

Coverage: *Cronartium ribicola*, white pine blister rust

Worldwide

Includes published and unpublished information on white pine blister rust covering its discovery in Europe and introduction to North America; laws, efforts to stop the infections, and also research knowledge gained.

2200 citations

20 citations per year

Base format: Bibliographic citations, keywords, abstracts

Retr. format: Computer printout/ 1 week
System used: FAMULUS
Computer center: Washington State Univ. Comput. Cent.
Compatible with: IBM 370

Retr. element: Author and title, *or* keywords

Contact:
Ray Hoff
Intermountain Forest and Range Exp. St.
1221 South Main Street
Moscow, ID 83843
(208) 882-3557
FTS (8) 554-1111

Availability: Forest Service, faculty, graduate students, corporation personnel, and other public agencies, for example, State of Idaho, BLM, and others/ free (Reprints on file at Forestry Sciences Lab., Moscow, Idaho.)

17 DRYING SCHEDULES FOR TROPICAL WOODS/ John McMillen / 1950

Coverage:	Kiln schedules, tropical woods Worldwide Describes drying characteristics and recommended kiln schedules of many tropical species. 500 citations 10 citations per year
Base format:	Summaries of data
Retr. format:	Letter/2 weeks; *or* verbal--by telephone
Retr. element:	Keywords plus species
Contact:	William Simpson Forest Products Laboratory P.O. Box 5130 Madison, WI 53705 (608) 257-2211 FTS (8) 362-2284
Availability:	Forest Service, faculty, graduate students, and industry/ free

18 ECOLOGY AND SILVICULTURE OF NORTHERN HARDWOODS/ Fred T. Metzger / 1966

Coverage:	Northern hardwoods, silviculture, regeneration, ecology Northeastern States Primarily concerned with ecology and ecological relationships to moisture, nutrients, and soils; regeneration practices, general silviculture and forest influences of northern hardwood and related forest types. 3500 citations 100 citations per year
Base format:	Bibliographic citations, subject matter converted to Oxford Forestry Classification
Retr. format:	Verbal--in person at site of data base
Retr. element:	Summary of information needed
Contact:	Fred T. Metzger North Central Forest Exp. St. 806 Wright Street Marquette, MI 49855 (906) 225-1323 FTS (8) 226-6000
Availability:	Forest Service, faculty, graduate students, and others/ free

19 ECONOMICS OF SURFACE MINE RECLAMATION/ Bill Plass / 1940

Coverage:	Surface coal mining, mining reclamation economics, ecological rehabilitation economics North America Comprehensive listing of publications dealing only with the economic aspects of surface coal mining reclamation. 450 citations 100 citations per year
Base format:	Bibliographic citations, keywords
Retr. format:	Photocopy / 1 week
Retr. element:	Author and title
Contact:	Jean W. Nolley Northeastern Forest Exp. St. P.O. Box 152 Princeton, WV 24740 (304) 425-8106 FTS (8) 924-4553
Availability:	Forest Service, faculty/ free

20 ENVIRONMENTAL PLANNING/ Arthur W. Magill / 1957

Coverage:	Outdoor recreation, ecology, environmental psychology, sociology, urban forestry, esthetics North America Primarily oriented toward outdoor recreation; chronologically reflects the originator's changing emphasis from ecological problems to the complex interrelationships between sociology, environmental psychology, esthetics, and planning in relation to wildlands, and finally, urban forestry. 2700 citations 150 citations per year
Base format:	Bibliographic citations, keywords, abstracts, reprints

Retr. format: Computer printout/ 2 weeks
System used: FAMULUS
Computer center: Lawrence Berkeley Laboratory
Compatible with: CDC 6000-7000

Retr. element: Author only, *or* title only, *or* author and title, *or* keywords

Contact: Librarian
Pacific Southwest Forest and Range Exp. St.
P.O. Box 245
Berkeley, CA 94701
(415) 486-3685
FTS (8) 449-3685

Availability: Forest Service, faculty, graduate students, and BLM, NPS, BOR, faculty and graduate students concerned with urban forestry, landscape architecture, environmental planning, psychology and sociology/ free

21 **FIBER AND PAPER PHYSICS/** Vance C. Setterholm / 1950

Coverage: Bonding, pulp properties, pulping, water sorption

Worldwide

Data is related to all phases of fiber and paper physics research with special emphasis on stress train investigations.

1400 citations

50 citations per year

Base format: Reprints

Retr. format: Letter/ 2 weeks; *or* verbal--by telephone or in person at site of data base

Retr. element: Keywords [Use: Subject List particular to this data base, provided upon request.]

Contact: Vance Setterholm
Forest Products Laboratory
P.O. Box 5130
Madison, WI 53705
(608) 257-2211 (ext.) 344
FTS (8) 364-2344

Availability: Forest Service, faculty, graduate students/ free

22 **FIRE/** Dale Wade / 1965

Coverage: Fire, fire management, fire behavior, fire ecology, forest fuels

Worldwide

Oriented toward all aspects of fire

5000 to 6000 citations

500 citations per year

Base format: Author and title references, bibliographic citations, keywords, abstracts, annotations, reprints, translations

Retr. format: Photocopy or letter/ 2 weeks; *or* verbal--by telephone or in person at site of data base

Retr. element: Author only, *or* author and title, *or* keywords

Contact: Dale Wade
Southern Forest Exp. St.
P.O. Box 938
Lehigh Acres, FL 33936
(813) 334-4579
FTS (8) 946-2011

Availability: Forest Service, faculty, graduate students, and others/ free

23 **FIREBASE/** Alan R. Taylor / 1974

Coverage: Forest fire, rangeland fires, prescribed fire, smoke, fire detection, fire suppression

Worldwide

Oriented toward all aspects of wildland fire, its management, use, control and research.

5000 citations

1500 citations per year

Base format: Bibliographic citations, keywords, abstracts, annotations, summaries of data, reprints, translations, references to published reports and nonprint media

Retr. format: Computer printouts, photocopy / 3 days; or verbal--by telephone

Retr. element: Summary of information needed

Contact: Ms. Karen L. Eckels
Boise Interagency Fire Center
3905 Vista Avenue
Boise, ID 83705
(208) 384-9457

FTS (8) 554-9457

Availability: Forest Service, faculty, graduate students, and others/ free

24 FIRE METEOROLOGY RESEARCH LIBRARY/ Robert S. Helfman / 1971

Coverage: Meteorology, weather, climate, topometeorology

North America

Collection of reports emphasizing topo scale and fire meteorology.

1425 citations

15 to 50 citations per year

Base format: Author and title references, bibliographic citations, keywords, abstracts, reprints

Retr. format: Computer printout/ 2 weeks
System used: FAMULUS
Computer center: Univ. Calif. Riverside Comput. Cent.
Compatible with: IBM 360/50

Retr. element: Author and title, *or* keywords

Contact: Robert S. Helfman
Pacific Southwest Forest and Range Exp. St.
P.O. Box 5007
Riverside, CA 92517
(714) 787-1572
FTS (8) 796-1572

Availability: Forest Service, faculty/ computer charges

25 FIRS/ George M. Hansen / 1970

Coverage: Forestry bibliography, forestry research

Pacific Northwest

Includes technical and nontechnical publications reporting on the Station's research on economics, forest engineering systems, forest and watershed management, insects and their control, pathology, range and wildlife habitat, recreation, regeneration, residues, resources inventories, and timber quality and yield potential.

1300 citations

250 citations per year

Base format: Bibliographic citations, keywords, abstracts, annotations

Retr. format: Computer printout/ 1 week
System used: FAMULUS
Computer center: Bonneville Power Adm., Portland
Compatible with: CDC 6400

Retr. element: Author only, *or* title only, *or* author and title, *or* keywords

Contact: Kay Sommerfeld
Pacific Northwest Forest and Range Exp. St.
P.O. Box 3141
Portland, OR 97208
(503) 234-3361 (ext.) 4925
FTS (8) 429-4925

Availability: Forest Service, faculty, graduate students, and others/ free

26 FOLIAGE AND TWIG DISEASES OF CONIFERS/ Glenn W. Peterson / 1960

Coverage: Brown spot, *DIPLODIA PINEA* twig and pine needle blight, western gall rust, *DOTHISTROMA NEEDLE BLIGHT*

Worldwide

Contains bibliographies on several shoot and foliage diseases. They contain worldwide literature on the diseases. These bibliographies have been sent to selected U.S. and foreign scientists periodically for additions and corrections, as well as for information.

830 citations

10 citations per year

Base format: Bibliographic citations

Retr. format: Photocopy / 1 week

Retr. element: Keywords, summary of information needed

Contact: Glenn W. Peterson
Rocky Mountain Forest and Range Exp. St.
East Campus, University of Nebraska
Lincoln, NB 68583
(402) 467-3556
FTS (8) 867-5211

Availability: Forest Service, faculty, graduate students in fields related to forestry and forestry related products/ free

27 **FOREST DISEASE RESEARCH/** E.P. Mieneke / 1911

Coverage: Forest pathology, plant pathology, mycology

Worldwide

Oriented toward plant disease, physiology, mycology; reflecting changing emphasis on disease research and control applications.

7925 citations

1000 citations per year

Base format: Author and title references, bibliographic citations, reprints

Retr. format: Letter/ 1 month; *or* verbal--by telephone or in person at site of data base

Retr. element: Author and title, *or* keywords

Contact:
Robert V. Bega
Pacific Southwest Forest and Range Exp. St.
P.O. Box 245
Berkeley, CA 94701
(415) 486-3155
FTS (8) 449-3155

Availability: Forest Service, faculty, graduate students, and others/ reproduction costs plus postage

28 **FOREST ECOSYSTEMS/** R.D. Pfister / 1960

Coverage: Silviculture, ecology, ecosystems, land classification

North America

Primarily oriented toward silviculture and synecology.

3000 citations

200 citations per year

Base format: Author and title references, bibliographic citations, reprints

Retr. format: Letter/ 1 week

Retr. element: Author and title, *or* summary of information needed

Contact:
R.D. Pfister
Intermountain Forest and Range Exp. St.
Drawer G University of Montana Campus
Missoula, MT 59801
(406) 329-3533
FTS (8) 585-3533

Availability: Forest Service, faculty, graduate students/ reproduction costs plus postage, $5 per hour for technicians' retrieval time.

29 **FOREST ENGINEERING/** R.B. Gardner / 1964

Coverage: Forest transportation, logging systems, slope stability, erosion

Worldwide

Relates to all phases of forest engineering, including road design, logging equipment and methods, logging systems analysis; using operations research techniques and industrial engineering techniques.

1500 citations

100 citations per year

Base format: Author and title references, bibliographic citations, keywords

Retr. format: Photocopy or letter/ 2 weeks; *or* verbal--by telephone or in person at site of data base

Retr. element: Keywords

Contact:
R.B. Gardner
Intermountain Forest and Range Exp. St.
P.O. Box 1376
Bozeman, MT 59715
(406) 994-4852
FTS (8) 585-4242

Availability: Forest Service, faculty/ free

30 **FOREST FERTILIZATION/** Luther Auchmoody / 1965

Coverage: Forest fertilization, foliar analysis, fertilizers

North America

Contains original reports dating from the early 1930's dealing with forest response and foliar nutrient levels, particularly in hardwood forests.

400 citations

50 citations per year

Base format: Bibliographic citations, keywords, reprints, authors

Retr. format: Photocopy or letter/ 1 week; *or* verbal--by telephone or in person at site of data base

Retr. element: Author and title, *or* summary of information needed

Contact:
Luther Auchmoody
Northeastern Forest Exp. St.
P.O. Box 928
Warren, PA 16315
(814) 563-7587
FTS (8) 722-3311

Availability: Forest Service, faculty, graduate students, and others/ free

31 FOREST FIRE/ Stephen Sackett / 1958

Coverage: Forest fuels, fire effects, prescribed burning

Worldwide

Includes fire bibliography; primarily prescribed fire and all aspects of forest fuels.

2000 citations

75 citations per year

Base format: Author and title, bibliographic citations, reprints (Reprints are to be used at Forestry Sciences Lab., ASU campus.)

Retr. format: Photocopy [photocopies of bibliographic cards sent upon request]/ 1 month

Retr. element: Author only, *or* keywords

Contact:
Stephen Sackett
Rocky Mountain Forest and Range Exp. St.
Arizona State University Campus
Tempe, AZ 85281
(602) 261-4365
FTS (8) 261-4365

Availability: Forest Service, faculty, graduate students/ free

32 FOREST FIRE RESEARCH/ John H. Dieterich / 1952

Coverage: Fire damage, fire suppression, fire physics, fire danger rating, prescribed burning, fuels, fire effects

Worldwide

Collection of reference material related to the prevention and suppression of forest fires and the use of fire as a management tool. Reflects the originator's changing responsibilities over the years, including fire control research, prescribed burning research, and fuels management research.

3000 citations

150 citations per year

Base format: Reprints

Retr. format: Verbal--by telephone [preferably], or in person at site of data base

Retr. element: Author and title, *or* keywords

Contact:
John H. Dieterich
Rocky Mountain Forest and Range Exp. St.
Arizona State University
Tempe, AZ 85281
(602) 261-4365
FTS (8) 261-4365

Availability: Forest Service, faculty, graduate students/ free

33 FOREST FIRE RETARDANT CHEMICALS AND EQUIPMENT/ Charles W. George / 1964

Coverage: Fire retardant effectiveness and treatment, chemicals, suppression, airtankers

Worldwide, primarily North America

Includes publications dealing with effectiveness of chemicals in altering pyrolysis and combustion formulations, additives, corrosion characteristics; mixing, handling and delivery systems; aerial delivery systems and retardant rheology.

1200 citations

50 to 100 citations per year

Base format: Author and title references, bibliographic citations, keywords, abstracts

Retr. format: Computer printout or photocopy / 2 weeks
System used: FAMULUS
Computer center: Lawrence Berkeley Laboratory
Compatible with: CDC 7600

Retr. element: Author and title, *or* keywords, *or* summary of information needed

Contact: Charles W. George
Intermountain Forest and Range Exp. St.
Drawer G University of Montana Campus
Missoula, MT 59806
(406) 329-3478
FTS (8) 585-3478

Availability: Forest Service, user groups from any agency/ free, unless one presents an unusually time-consuming request.

34 FOREST GENETICS/ Timothy LaFarge / 1965

Coverage: Forest genetics, tree improvement

Worldwide, primarily North America

A card file containing literature from all over the world concerning forest genetics.

About 4000 citations

[No longer adding citations to file]

Base format: Author and title references, some abstracts

Retr. format: Verbal--in person at site of data base

Retr. element: Author only, *or* title only, *or* subject area reference

Contact: Timothy LaFarge
Southern Forest Exp. St.
P.O. Box 5106
Macon, GA 31208
(912) 742-6347
FTS (8) 242-3110

Availability: Forest Service, faculty, graduate students, and others/ free

35 FOREST GENETICS AND BREEDING/ John F. Kraus / 1956

Coverage: Genetics, breeding, botany, biometry, pine

North America

Primarily concerned with genetics and breeding of *Pinus* with most emphasis on the southern pine.

2400 citations

100 citations per year

Base format: Bibliographic citations

Retr. format: Photocopy or letter/ 2 weeks

Retr. element: Author only

Contact: John F. Kraus
Southeastern Forest Exp. St.
P.O. Box 5106
Macon, GA 31208
(912) 742-6347
FTS (8) 238-0381

Availability: Forest Service, faculty, graduate students/ free

36 FOREST GENETICS AND PHYSIOLOGY/ Institute of Forest Genetics Scientific Staff / 1934

Coverage: Genetics, maximum yield silviculture, breeding, vegetative propagation

Worldwide

Data is in the form of reprints authored by scientists from all parts of the world. Subjects relate to basic tree physiology, (metabolism, photosynthesis, photosynthate compact, leaf area optimization), genetics, breeding, heritability, nutrient balance, and vegetative propagation.

3300 citations

800 citations per year

Base format: Author and title references, bibliographic citations, abstracts, reprints

Retr. format: Letter/ 1 month

Retr. element: Summary of information needed

Contact: David H. Dawson
North Central Forest Exp. St.
P.O. Box 898
Rhinelander, WI 54501
(715) 362-7474
FTS (8) 362-1012

Availability: Forest Service, faculty, graduate students, and others/ free

37 **FOREST HYDROLOGY/** Robert R. Ziemer / 1970

Coverage: Soil water, forest hydrology, landslides, slope stability, streamflow

Worldwide

Oriented to the field of forest hydrology. Designed primarily to aid in retrieval of author's collection of about 2500 reprints, plus other bibliographic citations. Emphasis is on soil moisture, tree root distribution, radioactive tracers, erosion, slope stability, landslides, and streamflow.

3000 citations

300 citations per year

Base format: Author and title references, bibliographic citations, keywords, abstracts, reprints, translations

Retr. format: Computer printout/ 1-2 weeks
Computer center: Colorado State Univ. Comput. Cent., Fort Collins
Compatible with: UNIVAC 1100

Retr. element: Summary of information needed

Contact: Jim Clarke
Pacific Southwest Forest and Range Exp. St.
P.O. Box 245
Berkeley, CA 94701
(415) 486-3708
FTS (8) 449-3708

Availability: Forest Service, faculty, graduate students, and others/ free, within reason

38 **FOREST HYDROMETEOROLOGY/** Lloyd W. Swift,Jr. / 1955

Coverage: Forest meteorology, forest climatology, forest hydrology, watershed management

North America

Personal file of keysort cards covering aspects of watershed management in humid areas with emphasis on meteorological effects.

2000 citations

100 citations per year

Base format: Bibliographic citations, annotations

Retr. format: Photocopy / 1 month

Retr. element: Author only, *or* title only, *or* keywords

Contact: Lloyd W. Swift, Jr.
Southeastern Forest Exp. St.
P.O. Box 601
Franklin, NC 28734
(704) 524-2128

Availability: Forest Service, faculty/ free

39 **FOREST AND MILL LABOR/** Forestry Sciences Laboratory / 1970

Coverage: Labor force, wood industry labor, manpower

Worldwide

Includes U.S. and foreign literature on labor in the forestry and wood industries. Excludes professional workers. Includes labor supply, demand, mobility, productivity, wages, working conditions, training, injuries, disease, and others. Emphasis on North America and Northern Europe. Base from 1920 to present.

1500 citations

100 citations per year

Base format: Bibliographic citations, keywords, country, industry, language

Retr. format: Computer printout/ 2 weeks
System used: FAMULUS
Computer center: Virginia Polytech. Instit. and State Univ., Blacksburg
Compatible with: IBM 370-365

Retr. element: Keywords, *or* summary of information needed, *or* search routine such as used by AGRICOLA

Contact: Jean W. Nolley
Northeastern Forest Exp. St.
P.O. Box 152
Princeton, WV 24740
(304) 425-8106
FTS (8) 924-4553

Availability: Forest Service, faculty, graduate students, industry, and other specialities/ free

40 FOREST PRODUCTS LAB SIMULATION MODEL/ Henry Spelter / 1977

Coverage: Economics, price, demand, forecasting

North America

Data base for the FPLSIM econometric model of the North American timber industries.

250 citations

50 or more citations per year

Base format: Data with code names

Retr. format: Computer printout/ 1 week
Computer center: Univ. of Wisc.-Madison Area Comput. Cent.
Compatible with: UNIVAC 1110

Retr. element: Keywords

Contact: Henry Spelter
Forest Products Laboratory
P.O. Box 5130
Madison, WI 53705
(608) 257-2211
FTS (8) 364-2364

Availability: Forest Service/ reproduction costs plus postage

41 FORESTRY/ Edwin Hebb / 1948

Coverage: Forestry, silviculture, ecology, environment

North America

General file on miscellaneous forestry topics. Emphasis is on silviculture and ecology.

10000 citations

200 citations per year

Base format: Author and title references, bibliographic citations, summaries of data, annotations

Retr. format: Verbal--in person at site of data base

Retr. element: Summary of information needed

Contact: Edwin A. Hebb
Southeastern Forest Exp. St.
P.O. Box 900
Marianna, FL 32446
(904) 482-4951
FTS (8) 946-2011

Availability: Forest Service, faculty, graduate students, and others/ free, but unable to handle a large number of requests

42 FOREST SERVICE RESEARCH/ Leonard DeBano / (Date Unknown)

Coverage: Soils, hydrology, forest, research, management

Worldwide

Contains information in the areas of forestry, soils, and hydrology; also research and management in these fields.

3400 citations

300 citations per year

Base format: Bibliographic citations, keywords, abstracts

Retr. format: Computer printout/ 2 weeks
System used: FAMULUS
Computer center: Arizona State Univ. Comput. Serv.
Compatible with: UNIVAC 1110

Retr. element: Author only, *or* title only, *or* author and title, *or* keywords (Use Leonard DeBano as keyword source; FTS (8) 261-4365)

Contact: Bill Casner
Rocky Mountain Forest and Range Exp. St.
Arizona State University
Tempe, AZ 85281
(602) 261-4365
FTS (8) 261-4365

Availability: Forest Service, faculty, graduate students/ reproduction costs plus postage

43 FOREST SITE QUALITY EVALUATION IN U.S./ Willard H. Carmean / 1950

Coverage: Site index, species indicators, growth intercept, soil types, soil-site

North America

Includes site index, species site index comparisons, growth intercept, plant indicators, physiographic site classification, soil survey, and soil-site methods.

481 citations

30 citations per year

Base format: Bibliographic citations, reprints

Retr. format: Letter/ 2 weeks; *or* verbal--by telephone

Retr. element: Author and title

Contact:
Willard H. Carmean
North Central Forest Exp. St.
1992 Folwell Avenue
St. Paul, MN 55108
(612) 645-0841
FTS (8) 784-1228

Availability: Forest Service, faculty, graduate students/ free

44 FOREST SOILS AND HYDROLOGY/ G.O. Klock / 1968

Coverage: Forest soils, hydrology, erosion, nutrient cycling

Worldwide

Serves as a working tool developed by originator to assist him with research in the field of forest soils and hydrology where access to a technical library is limited.

1400 citations

150 citations per year

Base format: Author and title references, keywords, reprints

Retr. format: Photocopy / 2 weeks

Retr. element: Author and title

Contact:
G.O. Klock
Pacific Northwest Forest and Range Exp. St.
1133 North Western Avenue
Wenatchee, WA 98801
(509) 662-4315
FTS (8) 390-0315

Availability: Forest Service, faculty, graduate students/ free

45 FOREST SOILS BIBLIOGRAPHY FOR NORTH CENTRAL REGION/ Willard H. Carmean / 1965

Coverage: Forest soils, site quality, tree nutrition, forest hydrology

North Central States

A bibliography that summarizes forest soils publications for the North Central region.

1093 citations

70 citations per year

Base format: Bibliographic citations, reprints

Retr. format: Letter/ 2 weeks; *or* verbal--by telephone

Retr. element: Author and title

Contact:
Willard H. Carmean
North Central Forest Exp. St.
1992 Folwell Avenue
St. Paul, MN 55108
(612) 645-0841
FTS (8) 784-0228

Availability: Forest Service, faculty, graduate students/ free

46 FOREST TAXATION/ William C. Siegel / 1975

Coverage: Forest taxation, income tax, capital gain, property tax, death tax, yield tax

North America

Collection of forest taxation literature published since 1950.

600 citations

40 citations per year

Base format: Author and title references, bibliographic citations, keywords, abstracts, annotations

Retr. format: Photocopy or letter/ 1 week; *or* verbal--by telephone

Retr. element: Author and title, *or* keywords

Contact:
William C. Siegel
Southern Forest Exp. St.
701 Loyola Avenue
New Orleans, LA 70113
(504) 589-6652
FTS (8) 682-6652

Availability: Forest Service, faculty, graduate students, and others/ free

47 FOREST WATER QUALITY/ Gordon Snyder / 1950

Coverage: Hydrology, water quality, snow, sediment, modeling

North America

Forest water quality management and topics related to nonpoint source pollution.

2000 citations

200 citations per year

Base format: Author and title references, bibliographic citations, reprints

Retr. format: Computer printout, photocopy / 2 weeks-1 month; *or* verbal-- by telephone

Retr. element: Author only, *or* title only, *or* author and title, *or* keywords

Contact:
Gordon Snyder
Intermountain Forest and Range Exp. St.
1221 South Main Street
Moscow, ID 83843
(208) 882-3557
FTS (8) 554-1111

Availability: Forest Service/ reproduction costs plus postage

48 FOREST WATERSHED/ R.L. Frederiksen / 1960

Coverage: Forest hydrology, soil erosion, nutrient cycles, environmental quality

Worldwide

Oriented toward the processes that conserve essential materials for the forest and the time span that such processes operate. Also includes water quality, stream processes affecting or affected by particulate and dissolved materials from the forest.

1200 citations

50 to 100 citations per year

Base format: Bibliographic citations, abstracts

Retr. format: Verbal--in person at site of data base

Retr. element: Author only *and* subject

Contact:
R.L. Frederiksen
Pacific Northwest Forest and Range Exp. St.
3200 Jefferson Way
Corvallis, OR 97331
(503) 757-4313
FTS (8) 420-4313

Availability: Forest Service, faculty, graduate students, and others/ free

49 FOREST WILDLIFE HABITAT/ Staff RWU-1702 / 1967

Coverage: Forest-wildlife relations, squirrels, wild turkeys, forest-multiple use, plant cover

Eastern North America

Oriented toward management of all species of forest wildlife and their recreational use in central Appalachia. Emphasis on habitat relationships.

7000 citations

500 citations per year

Base format: Bibliographic citations

Retr. format: Verbal--in person at site of data base

Retr. element: Keywords

Contact:
John Gill
Northeastern Forest Exp. St.
180 Canfield Street
Morgantown, WV 26505
(304) 599-7482
FTS (8) 923-7482

Availability: Forest Service, faculty, graduate students, and others/ free

50 GENETIC VARIATION OF *ARTEMISIA TRIDENTATA, ATRIPLEX CANDESCENS,* AND *CHRYSOTHAMNUS NAUSEOSUS*/ E.D. McArthur / 1973

Coverage: *Artemisia, Atriplex, Chrysothamnus,* genetics, variation

North America, with some extensions

The collection documents variation in these species complexes to help in studies in plant improvement.

170 citations

30 citatons per year

Base format: Bibliographic citations, reprints

Retr. format: Photocopy / 2 weeks

Retr. element: Author and title

Contact: E.D. McArthur
Intermountain Forest and Range Exp. St.
735 North 500 East
Provo, UT 84601
(801) 377-5717
FTS (8) 584-0218

Availability: Forest Service, faculty, graduate students, and others/ reproduction costs plus postage for large requests

51 **GLULAM/** Russell C. Moody / 1970

Coverage: Glulam, engineered timber, construction

Worldwide

Includes references on design and manufacture of glulam timber with an emphasis on strength properties.

1100 citations

30 citations per year

Base format: Author and title, bibliographic citations, keywords

Retr. format: Computer printout or photocopy / 2 weeks
System used: KWIC index
Computer center: Univ. Wisc.
Compatible with: Univac 1110

Retr. element: Keywords

Contact: Russell Moody
Forest Products Laboratory
P.O. Box 5130
Madison, WI 53705
(608) 257-2211 (ext.) 248
FTS (8) 364-2248

Availability: Forest Service, faculty, graduate students/ free

52 **GREAT PLAINS FORESTRY/** Ralph A. Read / 1955

Coverage: Windbreaks, shelterbelts, afforestation

Worldwide

Deals mainly with selection, establishment, and culture of trees in non-forest environment (primarily agricultural lands) for the purposes of environment modification, reduction of wind movement, moisture conservation, crop and animal protection, human protection, and landscape enhancement.

1768 citations

40 citations per year

Base format: Bibliographic citations

Retr. format: Verbal--by telephone

Retr. element: Author and title

Contact: Ralph A. Read
Rocky Mountain Forest and Range Exp. St.
University of Nebraska
Lincoln, NE 68583
(402) 467-3556
FTS (8) 867-5211

Availability: Forest Service, faculty/ reproduction costs plus postage

53 **GUDYSE/** B.H. Heede / 1960

Coverage: Gullies, gully plugs, fluvial geomorphology, stream gaging, sedimentation

Worldwide

Includes a personal file of published titles and abstracts from: Water Resources Research, Journal of the Hydraulics Division, ASCE Proceedings, Soil Science Society of America Journal, Zeitschrift fur Geomorphologie, Journal of Hydrology, and the Geological Society of America Bulletin.

2500 citations

100 citations per year

Base format: Bibliographic citations, abstracts, reprints, translations

Retr. format: Verbal--in person at site of data base (Computer printout available by summer, 1979).

Retr. element: Author and title

Contact:
Burchard H. Heede
Rocky Mountain Forest and Range Exp. St.
Arizona State University
Tempe, AZ 85281
(602) 261-4365
FTS (8) 261-4365

Availability: Forest Service, faculty, graduate students in fields related to forestry or forest products/ reproduction costs plus postage

54 **HACKBERRY (CELTIS) GALLMAKERS/** John C. Moser / 1950

Coverage: Hackberry, celtis, gallmakers

Worldwide

Includes taxonomy, biology, and ecology of galls and gallmakers of *Celtis.*

200 citations

5 citations per year

Base format: Author and title references

Retr. format: Letter/ 1 week; *or* verbal--by telephone

Retr. element: Author and title

Contact:
John C. Moser
Southern Forest Exp. St.
2500 Shreveport Highway
Pineville, LA 71360
(318) 445-6511
FTS (8) 497-3358

Availability: Forest Service, faculty, graduate students, and anyone interested/ free

55 **HARDWOOD SILVICULTURE/** David A. Marquis / 1956

Coverage: Forest ecology, silviculture, hardwoods, environmental factors

North America

Covers the topics listed above in *keywords*, primarily for the Northern hardwood and Allegheny hardwood forest types.

2000 citations

100 citations per year

Base format: Bibliographic citations, keywords, reprints

Retr. format: Photocopy or letter/ 1 week; *or* verbal--by telephone or in person at site of data base

Retr. element: Author and title, *or* summary of information needed

Contact:
David A. Marquis
Northeastern Forest Exp. St.
P.O. Box 928
Warren, PA 16365
(814) 563-7587
FTS (8) 722-3311

Availability: Forest Service, faculty, graduate students, and others/ free

56 **INSECT BORERS OF LIVING HARDWOOD TREES/** J.D. Solomon / 1961

Coverage: *Cossidae, Sesiidae, Cerambycidae, Buprestidae*, other families

North America

Concerned primarily with borer species causing economic damage, but also includes many other species in commercially important hardwood trees as well as other woody plants.

1200 citations

100 citations per year

Base format: Author and title references, bibliographic citations

Retr. format: Verbal--in person at site of data base

Retr. element: Summary of information needed

Contact:
J.D. Solomon
Southern Forest Exp. St.
P.O. Box 227
Stoneville, MS 38756
(601) 686-7218
FTS (8) 497-2404

Availability: Forest Service, faculty, graduate students, and others/ free

57 **INSECT PATHOLOGY-MICROBIAL CONTROL/** Staff NE-2202 / 1956

Coverage: Insect pathology, insect disease, NPV (nucleopolyhedrosis virus), CPV (cytoplasmicpolyhedrosis virus), bacteria

Worldwide

Includes world literature on insect disease, principally forest insects; bibliography ranges from very basic to very technical. Contains much medical literature.

3500 citations

100 to 200 citations per year

Base format: Author and title references, bibliographic citations, reprints

Retr. format: Letter/ 2 weeks

Retr. element: Author only, *or* title only, *or* author and title, *or* keywords

Contact:
F.B. Lewis
Northeastern Forest Exp. St.
151 Stanford Street
Hamden, CT 06514
(203) 432-2028
FTS (8) 643-8028

Availability: Forest Service, faculty, and graduate students in fields related to forestry or forest products/ reproduction costs plus postage

58 LARCH CASEBEARER/ Robert E. Denton / 1957

Coverage: Larch casebearer, biological control, chemical control, forest insect ecology

Worldwide

Oriented toward scientific investigations pertaining to the larch casebearer.

200 citations

10 citations per year

Base format: Bibliographic citations, keywords, abstracts

Retr. format:
Computer printout/ 2 weeks
System used: FAMULUS
Computer center: Wash. State Univ. Comput. Cent.
Compatible with: CDC 6400-6600, IBM 360, UNIVAC 1108

Retr. element: Author only, *or* title only, *or* author and title, *or* keywords

Contact:
Malcom M. Furniss
Intermountain Forest and Range Exp. St.
1221 South Main Street
Moscow, ID 83843
(208) 882-3557
FTS (8) 554-1111

Availability: Forest Service, faculty, graduate students/ free

59 LIGHTNING EFFECTS IN FORESTS/ Alan R. Taylor / 1964

Coverage: Atmospheric physics, lightning fires, lightning-struck trees

Worldwide

Oriented toward effects of lightning in forest and shrubland ecosystems; includes physiological and structural effects; literature on lightning-caused fire.

1600 citations

25 citations per year

Base format: Bibliographic citations, annotations, reprints

Retr. format: Photocopy or letter/ 3 days; *or* verbal--by telephone

Retr. element: Author and title, *or* keywords, *or* summary of information needed

Contact:
Alan R. Taylor
Intermountain Forest and Range Exp. St.
Drawer G University of Montana Campus
Missoula, MT 59806
(406) 329-3665
FTS (8) 585-3665

Availability: Forest Service, faculty, graduate students, and anyone interested/ free

60 LUMBER DRYING SCHEDULES/ John McMillen / 1940

Coverage: Kiln schedules, air drying

Worldwide

Principally a key to British and U.S.

kiln schedules by botanically separated or grouped species, most frequent or appropriate common names in U.S. Narrative on seasoning properties, most common problems, special problems (for example, resin exudation) and solutions.

1000 citations

5 citations per year

Base format: Bibliographic citations, abstracts, keywords, annotations, summaries of data

Retr. format: Letter/ 2 weeks

Retr. element: Supply botanical and common name of species; lumber thickness

Contact:
William T. Simpson
Forest Products Laboratory
P.O. Box 5130
Madison, WI 53705
(608) 257-2211
FTS (8) 362-2485

Availability: Forest Service, faculty, graduate students, and Industry/ free

61 MAPLE SYRUP DATA/ Lawrence D. Garrett / 1970

Coverage: Maple syrup, production costs, imports

North America

Includes a collection of statistics about the maple syrup products industry in the U.S. and Canada from 1860 to present.

100 citations

12 citations per year

Base format: Bibliographic citations, summaries of data

Retr. format: Photocopy / 2 weeks

Retr. element: Summary of information needed

Contact:
Paul E. Sendak
Northeastern Forest Exp. St.
P.O. Box 968
Burlington, VT 05402
(802) 862-6501
FTS (8) 832-6283

Availability: Forest Service, faculty/ free

62 MINNESOTA RESOURCES EVALUATION/ RWU-4101 / 1978

Coverage: Resources, inventory, tree volume

Individual states

Includes individual plant and tree records from state surveys.

111000 citations

100000 citations per year

Base format: Basic inventory data; raw data

Retr. format: Computer printout/ 1 month
System used: SZK
Computer center: Univ. Minn. Comput. Cent.
Compatible with: Cyber 74

Retr. element: Summary of information needed

Contact:
Jerold T. Hahn
North Central Forest Exp. St.
1992 Folwell Avenue
St. Paul, MN 55106
(612) 645-0841
FTS (8) 784-0281

Availability: Forest Service, faculty, State Department of Natural Resources personnel, forest industry woodland managers/ reproduction costs plus postage

63 MISTLETOE LITERATURE OF THE WORLD/ F.G. Hawksworth / 1960

Coverage: Mistletoe

Worldwide

Annotated list of the world's literature on mistletoe including historical as well as current information.

8500 citations

400 citations per year

Base format: Bibliographic citations, keywords, abstracts, annotations, translations, some newspaper articles and similar unserialized publications

Retr. format: Computer printout/ 1-2 weeks
System used: FAMULUS
Computer center: Colorado State Univ. Comput. Cent., Fort Collins

Compatible with: CDC 6600

Retr. element: Keywords (Use: MISTLETOE LITERATURE OF THE WORLD; A user's guide to a FAMULUS Retrieval System, General Technical Report RM-30, November, 1976)

Contact:
R.F. Scharpf
Pacific Southwest Forest and Range Exp. St.
P.O. Box 245
Berkeley, CA 94701
(415) 486-3156
FTS (8) 449-3156

AND

Contact:
F.G. Hawksworth
Rocky Mountain Forest and Range Exp. St.
240 West Prospect Street
Fort Collins, CO 80521
(303) 221-4390
FTS (8) 323-1246

Availability: Forest Service, faculty, graduate students, and others/ free

64 MITES ASSOCIATED WITH BARK BEETLES/ John C. Moser / 1962

Coverage: Mites, bark beetles, southern pine beetles

Worldwide

Concerned with mites associated with bark beetles, with emphasis on those associated with the southern pine beetle (*Dendroctonus frontalis*).

1000 citations

50 citations per year

Base format: Reprints

Retr. format: Letter/ 1 week; *or* verbal--by telephone

Retr. element: Author and title

Contact:
John C. Moser
Southern Forest Exp. St.
2500 Shreveport Highway
Pineville, LA 71360
(318) 445-6511 (ext.) 358
FTS (8) 497-3358

Availability: Forest Service, faculty, graduate students, and anyone interested/ free

65 MONOTERPENES OF CONIFERS/ A.E. Squillace / 1958

Coverage: Essential oils, turpentine, monoterpenes

Worldwide

A bibliography of monoterpenes of conifers. Permits a computer printout of references for a specified species.

435 citations

10 to 20 citations per year

Base format: Bibliographic citations

Retr. format:
Computer printout/ 2 weeks
System used: WANG disc retrieval
Computer center: Southern Forest Exp. St. Comput. Cent., Olustee
Compatible with: IBM 360-370

Retr. element: Summary of information needed

Contact:
A.E. Squillace *or* Betty Holiday
Southern Forest Exp. St.
P.O. Box 70
Olustee, FL 32072
(904) 752-0331
FTS (8) 946-2846

Availability: Forest Service, faculty, graduate students in forestry or forest products/ postage

66 MONTANA COOPERATIVE ELK-LOGGING STUDIES/ Eugene O. Allen / 1970

Coverage: Elk, logging, wildlife, land use

Worldwide

Primarily concerned with work done on elk and logging relationships. Other wildlife land use studies have been incorporated into the bibliography.

400 citations

50 citations per year

Base format: Author and title references, bibliographic citations, keywords, abstracts, summaries of data, reprints, unpublished reports

Retr. format:
Computer printout/ 2 weeks
System used: Citation Handler #1 Documentation Program
Computer center: Montana State Univ. Comput. Cent.
Compatible with: Xerox Sigma 7

Retr. element: Keywords (Use: keyword list particular to this bibliography), *or* summary of information needed

Contact:
Terry N. Lonner
P.O. Box 5
Montana State University
Bozeman, MT 59715
(406) 994-3285

Availability: Forest Service, faculty, graduate students, and others/ cost of computer time and cost of printout

67 MORPHOLOGY OF WOOD/ Irving B. Sachs / 1958

Coverage: Cell types, pitting, cell wall chemical composition and organization, reaction wood, pathology wood

Worldwide

Includes a file of literature citations that lends to a critical exegesis of the historical and present state of the knowledge of wood.

5000 citations

300 citations per year

Base format: Author and title references, bibliographic citations, reprints

Retr. format: Photocopy or letter/ 1 week; *or* verbal--by telephone or in person at site of data base

Retr. element: Author and title

Contact:
Irving B. Sachs
Forest Products Laboratory
P.O. Box 5130
Madison, WI 53705
(608) 257-2211 (ext.) 249
FTS (8) 364-2249

Availability: Forest Service, faculty, graduate students/ free

68 NATIVE CALIFORNIA HARDWOODS/ Philip M. McDonald / 1966

Coverage: Hardwoods, forestry, ecology

Worldwide

Oriented toward most abundant and useful native California hardwoods. Uses range from wood products to food for wildlife as well as providing esthetics, green fuel breaks, increased water yield and high incidence in urban forestry.

500 citations

20 citations per year

Base format: Author and title references, bibliographic citations

Retr. format: Letter/ 2 weeks; *or* verbal--by telephone

Retr. element: Author only, *or* title only

Contact:
Philip M. McDonald
Pacific Southwest Forest and Range Exp. St.
2400 Washington Plaza
Redding, CA 96001
(916) 246-5347
FTS (8) 461-5347

Availability: Forest Service, faculty, graduate students, and others/ free

69 OAK WILT AND LIVE OAK DECLINE/ Bill McDonald / 1964

Coverage: Transmission, survey

North America

Limited to the oak wilt and live oak decline fungus (*Ceratocystis fagacearum*)

880 citations

10 citations per year

Base format: Author and title references, bibliographic citations, keywords

Retr. format: Photocopy / 2 weeks

Retr. element: Author and title

Contact:
Forrest Lee Oliveria
Southern Forest Exp. St.
P.O. Box 227
Stoneville, MS 38776
(601) 686-7218
FTS (8) 497-2404

Availability: Forest Service/ free

70 OPERATIONS RESEARCH RELATED TO FIRE MANAGEMENT/ James B. Davis / 1965

Coverage: Modeling, assimilation, fires, fire planning

North America

Includes fire history and occurrence, studies on the transportation and travel time to fires, inventory on firefighting resources for a given forest, cooperating resources, and manning and dispatching resources.

400 citations

15 citations per year

Base format: Author and title references, bibliographic citations, abstracts

Retr. format: Letter/ 1 week, *or* verbal--by telephone or in person at site of data base

Retr. element: Author only, *or* title only, *or* summary of information needed

Contact:
James B. Davis
P.O. Box 2417
Forest Service
Washington, D.C. 20013
(703) 235-8195
FTS (8) 235-8195

Availability: Forest Service, faculty, graduate students/ free

71 OPTICAL RETRIEVAL FOR FOREST GENETICS LITERATURE/ E. Bayne Snyder / 1955

Coverage: Genetics, breeding, pines

Southeastern States

Publications cross indexed as to species, reproductive biology, and artificial pollination procedures; selection and breeding methods and results; variation and inheritance among taxa; among populations and within populations; juvenile, mature and genotype-environment relationships; and progeny test methods and results.

10000 citations

500 citations per year

Base format: Bibliographic citations, keywords

Retr. format: Verbal--in person at site of data base

Retr. element: Keywords (Use: list of 1600 keywords at site of data base)

Contact:
E. Bayne Snyder
Southern Forest Exp. St.
P.O. Box 2008
Gulfport, MS 39503
(601) 864-3461
FTS (8) 499-2632

Availability: Forest Service, faculty, graduate students, and others/ free

72 OUTDOOR RECREATION RELATED LITERATURE/ Robert C. Lucas / 1960

Coverage: Wilderness, recreation, research

Primarily North America

Wide assortment of publications of last 20 years, generally relating to outdoor recreation.

1400 citations

70 citations per year

Base format: Author and title references, bibliographic citations, keywords

Retr. format: Verbal--in person at site of data base

Retr. element: Keywords, (Use: keyword source particular to this data base)

Contact:
Robert C. Lucas
Intermountain Forest and Range Exp. St.
Drawer G University of Montana
Missoula, MT 59801
(406) 329-3533
FTS (8) 585-3533

Availability: Forest Service, faculty, and graduate students/ free

73 OUTSIDE STORAGE OF PULPWOOD CHIPS/ George J. Hajny / 1966

Coverage: Chip storage, chip degradation, tall oil loss, preservation

Worldwide

A collection of references in abstract form about all aspects of outside chip storage, such as methods of pile building, wood and by-product losses, fire hazard, storage time, pulp yields and quality, and methods of control of pulp chip degradation.

425 citations

50 citations per year

Base format: Bibliographic citations, abstracts

Retr. format: Photocopy / 1 month

Retr. element: Summary of information needed

Contact:
Edward L. Springer
Forest Products Laboratory
P.O. Box 5130
Madison, WI 53705
(608) 257-2211
FTS (8) 364-2234

Availability: Forest Service, faculty, technical personnel in the pulp and paper industry/ free

74 OXFORD SYSTEM OF DECIMAL CLASSIFICATION FOR FORESTRY, FOREST HYDROLOGY, AND WATERSHED MANAGEMENT RESEARCH--RWU 1602/ S.J. Ursic / 1950

Coverage: Forest watershed management, hydrology, nonpoint source pollution, forest soils, erosion control

Worldwide

Covers all phases of forest hydrology and watershed management research, especially Southern coastal plain but also regions outside the south. Expanded particularly in the area of site factors.

8500 citations

300 citations per year

Base format: Bibliographic citations

Retr. format: Verbal--in person at site of data base

Retr. element: Author and title

Contact:
Sarah S. Knight
Southern Forest Exp. St.
P.O. Box 947
Oxford, MS 38655
(601) 234-2744
FTS (8) 490-4211

Availability: Forest Service, faculty, graduate students, and others/ reproduction costs plus postage

75 PARTICLE BOARD/ Robert Geimer / 1973

Coverage: Particle board, reconstituted wood, physical properties, fabrication, test methods

Worldwide

Concerned with the design, fabrication, techniques, physical propertes, testing, production statistics, characteristics, and uses of particle board and flakeboard made from a variety of material types.

1144 citations

150 citations per year

Base format: Bibliographic citations, keywords, abstracts

Retr. format:
Computer printout/ 2 weeks
System used: FAMULUS
Computer center: Univ. of Wisc. Comput. Cent.
Compatible with: IBM 360-370

Retr. element: Author only, *or* title only, *or* keywords

Contact:
Robert Geimer
Forest Products Laboratory
P.O. Box 5130
Madison, WI 53705
(608) 257-2211
FTS (8) 364-2385

Availability: Forest Service, faculty, graduate students, and others/ cost dependent on size and number of requests

76 PHYSIOLOGY OF DROUGHT AND COLD RESISTANCE/ Johnson Parker / 1949

Coverage: Drought, cold, stress, sugars, phenols

Worldwide

Concerns effects of drought and cold on woody plants, including changes in sugars, phenols, and amino acids; natural causes of resistance to drought and cold in physical and chemical terms; and chromatographic techniques.

5300 citations

Approximately 100 citations per year

Base format: Bibliographic citations, abstracts, keywords

Retr. format: Photocopy / 1 week

Retr. element: Author only, *or* keywords, *or* author and title

Contact:
Johnson Parker
Northeastern Forest Exp. St.
151 Sanford Street
Hamden, CT 06514
(203) 432-2011
FTS (8) 643-8011

Availability: Forest Service, faculty, graduate students/ free

77 *PINUS MONTICOLA*/ Ray J. Hoff / 1976

Coverage: Western white pine

Worldwide

Includes all published and unpublished information concerning *Pinus monticola*; western white pine

400 citations

150 citations per year

Base format: Bibliographic citations, abstracts, keywords

Retr. format:
Computer printout, letter/ 1 week
System used: FAMULUS
Computer center: Wash. State Univ. Comput. Cent.
Compatible with: IBM 370

Retr. element: Author and title, *or* keywords

Contact:
Ray Hoff or Jan Qualls
Intermountain Forest and Range Exp. St.
1221 South Main Street
Moscow, ID 83843
(208) 882-3557
FTS (8) 554-1111

Availability: Forest Service, faculty, graduate students, and all corporation personnel and other public agencies, for example, State of Idaho, Bureau of Land Mangement, and others/ free

78 **PLAIN/** Northern Great Plains Resources Program / 1974

Coverage: Surface resources, mineral resources, atmospheric aspects, regional geology, water resources, socioeconomic and cultural aspects.

Northern Great Plains

PLAIN is tabular data from 13 volumes of Northern Great Plains Resources program study stored on 7- and 9- track magnetic tapes.

607 tables

No citations added, tables updated periodically

Base format: Summaries of data, tables of data

Retr. format:
Computer printout/ 1 week
System used: FORTRAN IV
Computer center: Colorado State Univ. Comput. Cent., Fort Collins
Compatible with: UNIVAC 1108 with Exec. 8 operating system

Retr. element: A list of tables supplied via user's manual. (Use: Manual for Accessing PLAIN data by Steve Kleinschmidt, Colorado State University, 1976)

Contact:
Program Manager, SEAM
Intermountain Forest and Range Exp. St.
145 Grand Avenue
Billings, MT 59101
(406) 657-6468
FTS (8) 585-6468

Availability: Forest Service, faculty, graduate students, and others/ free

79 **PUBLICATIONS LIST/** Glen E. Brink / 1953

Coverage: List of publications

Rocky Mountains Region

Citations and annotations published by Rocky Mountain Station covering all areas of research. Also included are citations and annotations of the station scientists' journals, technical papers, etc.

1600 citations

120 citations per year

Base format: Author and title references, bibliographic citations, annotations

Retr. format:
Computer printout/ 1 month
System used: NOS
Computer center: Colorado State Univ. Comput. Cent., Fort Collins

Compatible with: CDC Cyber 172

Retr. element: Author only, *or* author and title

Contact:
Glen E. Brink
Rocky Mountain Forest and Range Exp. St.
240 West Prospect Street
Fort Collins, CO 80521
(303) 221-4390
FTS (8) 323-1489

Availability: Forest Service/ computer charges

80 **PULPWOOD PRODUCTION AND RECEIPTS/** Neal P. Kingsley / 1963

Coverage: Pulpwood, mill receipts, timber harvesting, primary productivity, manufacturing residues

Northeastern States

Contains data about pulpwood chip production from roundwood in 14 Northeastern states by counties and species groups, pulpwood chip production from plant residues, and production of total tree chips.

27000 citations

1800 citations per year

Base format: Summaries of data

Retr. format: Photocopy or letter/ 2 weeks, *or* verbal--by telephone

Retr. element: Keywords, (Use: Pulpwood Production in the Northeast, [Northeastern Forest Experiment Station, Resource Bulletin NE-3 or NE-5])

Contact:
James T. Bones
Northeastern Forest Exp. St.
370 Reed Road
Broomall, PA 19008
(215) 596-1645
FTS (8) 596-1645

Availability: Forest Service, faculty/ reproduction costs plus postage

81 **RANGE MANAGEMENT PUBLICATIONS FILE/WILDLIFE MANAGEMENT SUBJECT 26W/** Range and Wildlife Management Staff Unit-Region 2 / 1954

Coverage: Range management, wildlife management

Worldwide

A staff unit file containing published materials collected over the years and catalogued by 38 Range management and 83 Wildlife management categories.

3383 citations

50 to 55 citations per year

Base format: Bibliographic citations, topical subject categories

Retr. format: Verbal--in person at site of data base

Retr. element: Author and title

Contact:
W.B. Gallaher
Rocky Mountain Forest and Range Exp. St.
11177 West 8th Avenue
P.O. Box 25127
Lakewood, CO 80225
(303) 234-4011
FTS (8) 234-4011

Availability: Forest Service, faculty, graduate students, and others/ reproduction costs plus postage

82 **RANGE MANAGEMENT RESEARCH/** Raymond D. Ratliff / 1960

Coverage: Range management, grassland ecology, meadows, range ecosystem

North America

Oriented toward various aspects of range management research (including fire, wildlife, recreation, livestock) developed for personal use.

980 citations

50 citations per year

Base format: Author and title references

Retr. format: Verbal--in person at site of data base

Retr. element: Author and title

Contact:
Raymond D. Ratliff
Pacfic Southwest Forest and Range Experiment Station
Federal Building
1130 "O" Street
Fresno, CA 93721
(209) 487-5194
FTS (8) 467-5194

Availability: Forest Service, faculty/ free

83 RANGE MANAGEMENT RESEARCH PROJECT LIBRARY/ Henry A. Pearson / 1945

Coverage: Range management, forest range, ecology, prescribed burning, livestock management, southern pines

Primarily Southeastern States

Contains early and current literature on forest grazing, range plants, range improvements, plant ecology and taxonomy and related pine forestry in the southern U.S., primarily longleaf-slash pine timber type.

3000 citations

75 citations per year

Base format: Author and title references, bibliographic citations

Retr. format: Photocopy or letter/ 1 week; *or* verbal--by telephone or in person at site of data base

Retr. element: Author and title

Contact:
Voylene Gill
Southern Forest Exp. St.
2500 Shreveport Highway
Pineville, LA 71360
(318) 445-6511 (ext.) 373
FTS (8) 497-3373

Availability: Forest Service, faculty, graduate students/ free

84 RECREATION-DURHAM LABORATORY/ Wilbur LaPage / 1963

Coverage: Planning, management, economics, research

North America

Publications are categorized by activity and the keywords, that is, camping, management, visitor services; or skiing, economics, demand studies; or hiking, planning, trail construction. Publications are indexed on keysort cards with a cross-reference by author.

1000 citations

15 to 20 citations per year

Base format: Author and title references, bibliographic citations

Retr. format: Verbal--in person at site of data base

Retr. element: Author only, *or* keywords, (Use keyword source, particular to this data base; available at Durham Lab.)

Contact:
H.E. Echelberger
Northeastern Forest Exp. St.
Concord-Mast Road
P.O. Box 640
Durham, NH 03824
(603) 868-5576 or 9697
FTS (8) 834-0797 or 0798

Availability: Forest Service, faculty, graduate students, and others/ free

85 REHABILITATION OF WESTERN WILDLANDS/ Stephen B. Monsen / 1961

Coverage: Revegetation, plant cover, vegetation establishment

Worldwide

Information is related to selection, propagation, and use of plant materials for wildland sites. Includes ecology of plant communities; seed and vegetative characteristics; the forage, watershed, and habitat usefulness of each species. Also, techniques and procedures useful in planting and propagating native and introduced grasses, broadleaf herbs and shrubs. Principal attention has been given to species endemic to the Western U.S.

1500 citations

150 to 250 citations per year

Base format: Author and title references, bibliographic citations, abstracts, summaries of data

Retr. format: Photocopy or letter/ 2 weeks-1 month

Retr. element: Author and title, *or* keywords

Contact:
Stephen B. Monsen
Intermountain Forest and Range Exp. St.
316 East Myrtle Street
Boise, ID 83706
(208) 384-1457
FTS (8) 554-1457

Availability: Forest Service, faculty, graduate students, and others/ reproduction costs plus postage

86 **REMOTE SENSING FOR RENEWABLE RESOURCE INVENTORY/** Richard S. Driscoll / 1965

Coverage: Remote sensing, resource information, resource analysis, stress analysis

Worldwide

Deals with experimental and operational remote sensing applications for resources inventories and evaluation.

1200 citations

100 citations per year

Base format: Bibliographic citations, keywords

Retr. format: Computer printout/ 2 weeks
System used: FAMULUS
Computer center: Colorado State Univ. Comput. Cent., Fort Collins
Compatible with: CDC Cyber 171/172

Retr. element: Author and title, *or* keywords

Contact: Richard S. Driscoll
Rocky Mountain Forest and Range Exp. St.
240 West Prospect Street
Fort Collins, CO 80521
(303) 221-4390
FTS (8) 323-1229

Availability: Forest Service, faculty, graduate students/ free

87 **REMOTE SENSING REFERENCE COLLECTION/** Rangeland Inventory and Evaluation Program 1707 / 1969

Coverage: Remote sensing, aerial photographs, natural resources

Worldwide

Includes literature on remote sensing, ranging from technical reports to popular articles. Emphasis is on techniques, equipment, data analysis, and applications, especially concerning natural resource inventory.

1150 citations

100 citations per year

Base format: Bibliographic citations, keywords, reprints, federal reports

Retr. format: Computer printout/ 2 weeks; *or* verbal--in person at site of data base
System used: FAMULUS
Computer center: Colorado State Univ. Comput. Cent., Fort Collins
Compatible with: CYBER/CDC 6000

Retr. element: Author only, *or* title only, *or* keywords (Use: keyword list particular to this data base), *or* summary of information needed

Contact: Richard S. Driscoll
Rocky Mountain Forest and Range Exp. St.
240 West Prospect Street
Fort Collins, CO 80521
(303) 221-4390
FTS (8) 323-1264

Availability: Forest Service, faculty, graduate students, and others/ free

88 **RESIN EXTRACTION FROM THE LIVING PINE/** Ralph W. Clements / 1943

Coverage: Oleoresin, flow patterns, flow measurement, techniques, chemical treatments

Worldwide

Includes recommended techniques, methods, and chemicals for resin production from conifers. Physiological reasoning for flow, effect on tree, tabulated yields by diameter classes, integration of resin, and timber production. Also an illustrated manual of techniques, treatments, tools and equipment, costs and returns.

2600 citations

50 citations per year

Base format: Bibliographic citations, abstracts, summaries of data, reprints, keywords, over 500 black-and-white photographs

Retr. format: Photocopy or letter/ 2 weeks; *or* verbal--in person at site of data base

Retr. element: Summary of information needed

Contact: Ralph W. Clements
Southeastern Forest Exp. St.
P.O. Box 70
Olustee, FL 32072
(904) 752-0331 or 0332

FTS (8) 946-2846 or 2847

Availability: Forest Service, faculty, graduate students, and scientists and technical people from foreign countries/ free

89 RESOURCES EVALUATION/ John Cosgrove / 1953

Coverage: Forest inventory, resource evaluation

North Central States

Includes forest survey publications published by the Lake States Forest Experiment Station and the North Central Forest Experiment Station since 1953. Publications report findings of forest inventories including forest area, timber volume, growth, mortality, timber production and consumption.

280 citations

15 citations per year

Base format: Bibliographic citations, keywords, abstracts

Retr. format: Computer printout/ 2 weeks
System used: TRIAL (Technique for Retrieving Information from Abstracts of Literature)
Computer center: Dep. Comput. Sci., Northwestern Univ., Evanston
Compatible with: IBM 709, IBM 360, CDC 3400, CDC 6000, CDC 6400

Retr. element: Author and title, *or* keywords, *or* summary of information needed

Contact:
Pamela Jakes
North Central Forest Exp. St.
1992 Folwell Avenue
St. Paul, MN 55175
(612) 645-0841 (ext.) 308
FTS (8) 784-0308

Availability: Forest Service, faculty, graduate students, state natural resource departments, planning agencies, and others/ free

90 RESOURCE EVALUATION REMOVALS PHASE/ James T. Bones / Date Unknown

Coverage: Pulpwood, timber, output, northeast, removal cuttings, resource management

Northeastern States

Contains periodic assessments of regional pulpwood and timber output based upon canvasses of the pulpmills and timber harvesting firms and state forestry organizations in the Northeast. Also contains data on total production and trends.

300000 citations

1500 citations per year

Base format: Bibliographic citations, keywords, abstracts, summaries of data

Retr. format: Photocopy or letter/ 1 week; *or* verbal--by telephone or in person at site of data base

Retr. element: Author and title, *or* keywords, *or* bibliographic citations

Contact:
Robert L. Nevel, Jr.
Northeastern Forest Exp. St.
370 Reed Road
Broomall, PA 19026
(215) 596-1984
FTS (8) 596-1984

Availability: Forest Service, faculty, graduate students, and state foresters, pulpmills, sawmills, business analysts, commerce departments/ free

91 RIVER RECREATION/ David Lime / 1975

Coverage: Resource impact, classification, esthetics, management, research

Worldwide, primarily North America

River recreation is experiencing widespread growth and popularity and as a result has become a major area for planning, management, and research. More than 300 citations documenting various aspects of the river recreation resource are presented.

400 citations

25 citations per year

Base format: Author and title references, bibliographic citations, keywords, abstracts, annotations

Retr. format: Publication/ 1 month

Retr. element: Keywords (Use: publication, titled: Annotated Bibliography on River Recreation)

Contact:
David Lime
North Central Forest Exp. St.
1992 Folwell Avenue
St. Paul, MN 55108
(612) 645-0841
FTS (8) 784-0274

Availability: Forest Service, faculty, graduate students, and others/ free

92 SAGEBRUSH IN THE WESTERN UNITED STATES/ Roy Harniss / 1977

Coverage: Distribution, autecology, synecology, management

North America

Includes material from 1900 to 1978.

1250 citations

50 citations per year

Base format: Bibliographic citations, keywords

Retr. format:
Computer printout/ 2 weeks
System used: FAMULUS
Computer center: Washington State Univ. Comput. Cent.
Compatible with: IBM 360

Retr. element: Author only, *or* author and title

Contact:
Elizabeth Close or Roy Harniss
Intermountain Forest and Range Exp. St.
507 25th Street
Ogden, UT 84401
(801) 399-3370 or 752-1311
FTS (8) 586-3697

Availability: Forest Service, faculty, graduate students, and others, for example, BLM, SCS, NPS/ reproduction costs plus postage

93 SAGEBRUSH INSECT COMPLEX/ Charles Tiernan / 1975

Coverage: *Artemisia* spp., shrubs, insects

North America

Concerned with the ecological effect of insects associated with growth and reproduction of sagebrush, section *Tridentatae*, and methods of pest control.

60 citations

[New entries appear as frequently as possible]

Base format: Author and title references, bibliographic citations, reprints

Retr. format: Letter/ 1 month

Retr. element: Author only, *or* title only, *or* author and title, *or* keywords

Contact:
Charles Tiernan
Intermountain Forest and Range Exp. St.
735 North 500 East
Provo, UT 84601
(801) 377-5717
FTS (8) 584-0218

Availability: Forest Service, faculty, graduate students, and others/ free

94 SAND PINE-SANDHILLS REFORESTATION/ R.H. Brendemuehl / 1974

Coverage: Sand pine, sandhills, reforestation

Southeastern States

Limited to literature concerned with sandhill regions of Southeastern U.S., droughty soils, vegetation, reforestation, and management practices.

250 citations

20 citations per year

Base format: Bibliographic citations

Retr. format: Photocopy / 2 weeks

Retr. element: Author and title

Contact:
R.H. Brendemuehl
Southeastern Forest Exp. St.
P.O. Box 900
Marianna, FL 32446
(904) 482-4051
FTS (8) 946-2011

Availability: Forest Service, faculty, graduate students in forestry or forest products/ reproduction costs plus postage

95 SEWAGE RECYCLING ON FORESTS/ Dean H. Urie / 1971

Coverage: Effluents, sludge, sewage, forests, water quality

Worldwide

Primarily covers forest and wildland uses of sewage and sewage treatment products as use on land affects water quality, plant growth, fate of nutrients and metals. Includes some microbiological references.

500 citations

100 citations per year

Base format: Author and title references, bibliographic citations, keywords, abstracts, annotations

Retr. format: Photocopy / 2 weeks

Retr. element: Author and title, *or* summary of information needed

Contact:
Dean Urie
North Central Forest Exp. St.
1407 South Harrison Street
East Lansing, MI 48823
(517) 355-7740
FTS (8) 375-7740

Availability: Forest Service, faculty, graduate students/ reproduction costs plus postage

96 SILVICULTURE FAMULUS/ Robert E. Martin / 1975

Coverage: Silviculture, soil types, fire behavior, range, seeds

Worldwide

Covers many subjects related to fire and fuels, range, silviculture, soils and plant growth.

4500 citations

1000 citations per year

Base format: Author and title, bibliographic citations

Retr. format:
Computer printout/ 2 months
System used: FAMULUS
Computer center: Bonneville Power Adm., Portland
Compatible with: CDC 6500

Retr. element: Keywords

Contact:
Robert E. Martin
Pacific Northwest Forest and Range Exp. St.
1027 North West Trenton Avenue
Bend, OR 97701
(503) 382-6922
FTS (8) 422-6283

Availability: Forest Service, faculty, graduate students, and others/ reproduction costs plus postage; also must send tape for duplication

97 SILVICULTURE OF CUMBERLAND PLATEAU AND HIGHLAND RIVER FORESTS/ Arnold Mignery / 1957

Coverage: Soils, artificial regeneration, growth and yield, site classification

Midsouth-Cumberland plateau and river

Reprints of articles; research papers on soils, regeneration and silviculture.

8000 citations

150 citations per year

Base format: Author and title references, keywords, abstracts, annotations, reprints

Retr. format: Verbal--in person at site of data base

Retr. element: Author only

Contact:
Roger Best
Southern Forest Exp. St.
P.O. Box 1290
Sewanee, TN 37375
(615) 598-5854
FTS (8) 222-3011

Availability: Forest Service, faculty, graduate students/ free, depending on the size of request

98 SILVICULTURE OF FOREST MANAGEMENT/ Dale O. Hall / 1956

Coverage: Silviculture, forest management, forest economics, forest biomass, tree ecosystems

North America

Emphasizing plant ecology, artificial and natural regeneration, all-aged and even-aged silvicultural systems, timber stand improvement regulation and economic rotations, stand phytomass and ecosystem modeling. Specialization is western silviculture, emphasizing ponderosa pine.

6000 citations

300 citations

Base format: Bibliographic citations, keywords, abstracts, annotations, reprints, translations

Retr. format: Computer printout or photocopy / 1-2 weeks
System used: FAMULUS
Computer center: Washington State Univ. Comput. Cent.
Compatible with: IBM 360-67

Retr. element: Author only, *or* keywords, (Use:Oxford Decimal Classification System)

Contact: Dale O. Hall
Intermountain Forest and Range Exp. St.
316 Myrtle Street
Boise, ID 83706
(208) 384-1457
FTS (8) 554-1457

Availability: Forest Service, graduate students in forestry or forest products/ direct computer costs

99 SILVICULTURE, MOUNTAINS AND PLAINS, WESTERN U.S./ Charles E. Boldt / 1960

Coverage: Silviculture, ponderosa pine, northern plains

Western States

Primarily a collection of reprints and texts, relating to silviculture of conifers and deciduous trees in mountains and plains of the North Central United States.

3000 to 4000 citations

100 or more citations per year

Base format: Bibliographic citations, annotations, reprints

Retr. format: Verbal--in person at site of data base

Retr. element: Keywords, *or* summary of information needed

Contact: Charles Boldt
Rocky Mountain Forest and Range Exp. St.
South Dakota School of Mines and Technology
Rapid City, SD 57701
(605) 343-0811
FTS (8) 782-1451

Availability: Forest Service, faculty, graduate students, and others/ free

100 SOILS AND FOREST ECOSYSTEM MANAGEMENT, SOUTHWEST/ Ralph E. Campbell / 1960

Coverage: Ponderosa pine, fire effects, nutrient cycling, water quality

North America

File consists of reprints relating mostly to forest ecosystem management with a primary interest in soil. It is cross-referenced by author and subject keywords.

2000 citations

200 citations per year

Base format: Author and title references, bibliographic citations, reprints

Retr. format: Photocopy or letter/ 1 week; *or* verbal--by telephone or in person at site of data base

Retr. element: Author and title, *or* keywords

Contact: Ralph E. Campbell
Rocky Mountain Forest and Range Exp. St.
Northern Arizona University
Flagstaff, AZ 86001
(602) 779-3311 (ext.) 1521
FTS (8) 261-1521

Availability: Forest Service, faculty, graduate students, and others/ reproduction costs plus postage

101 SOUTHERN HARDWOODS REFERENCE FILE-RWU 1402/ R.A. Daniels / 1977

Coverage: Genetic variation, phenotypes, species, taxonomy

Southern North America-East of Central Texas

Contains all known information on the genetics of southern hardwood tree species. Topics include phenology, natural variation, reproduction, progeny and provenance testing, taxonomy, and vegetative propagation.

150 citations

25 or more citations per year (but will soon be increasing at a greater rate)

Base format: Author and title references, bibliographic citations

Retr. format: Letter/ 2-3 weeks (will eventually become available on a computer printout)

Contact:
R.A. Daniels
Southern Forest Exp. St.
P.O. Box 906
Starkville, MS 39759
(601) 323-8163
FTS (8) 490-4509

Availability: Forest Service, faculty/ postage costs

102 **TIMBER HARVESTING LITERATURE LIBRARY/** Harry G. Gibson / 1965

Coverage: Logging, timber harvesting, loading, skidding, trucking, felling, logging costs

Worldwide

15000 citations

400 citations per year

Base format: Author and title references, reprints

Retr. format: Letter/ 2 weeks; *or* verbal--by telephone or in person at site of data base

Retr. element: Keywords, *or* summary of information needed

Contact:
Cleveland J. Biller
Northeastern Forest Exp. St.
180 Canfield Street
Morgantown, WV 26505
(304) 599-7483
FTS (8) 923-7483

Availability: Forest Service, faculty, graduate students, and others/ free

103 **TIMBER MANAGEMENT/** RWU PSW-1201 / 1960

Coverage: Timber management, silviculture, nutrition, fuels management, plant physiology

North America

Oriented toward timber management research and problem assignments which include silvicultural systems, silvics, ecology, regeneration, competing vegetation, stocking, growth and yield, forest nutrition, and fuels management.

75000 citations

800 citations per year

Base format: Author and title references, bibliographic citations, keywords

Retr. format: Photocopy or letter/ 1 week; *or* verbal--by telephone or in person at site of data base

Retr. element: Author and title, *or* keywords, *or* summary of information needed

Contact:
Douglass F. Roy
Pacific Southwest Forest and Range Exp. St.
2400 Washington Avenue
Redding, CA 96001
(916) 246-5455
FTS (8) 461-5455

Availability: Forest Service, faculty, graduate students, and others/ reproduction costs plus postage

104 **TREE HAZARD AND DISEASE/** Lee A. Paine / 1951

Coverage: Hazards, safety standards, tree diseases, recreation sites, urban forestry

Western Hemisphere

Primarily concerned with tree hazards on managed sites, hazards to people and property in urban and non-urban areas. Evaluation of hazard, detection and evaluation of defects; control of hazards, and information on the setting of safety control standards and hazard standards.

5000 citations

200 to 300 citations per year

Base format: Bibliographic citations

Retr. format: Verbal--in person at site of data base

Retr. element: Keywords

Contact:
Lee A. Paine
Pacific Southwest Forest and Range Exp. St.
P.O. Box 245
Berkeley, CA 94701
(415) 486-3158
FTS (8) 449-3158

Availability: Strictly available to visitors on site/ free

105 **T-PATH (TREE PATHOLOGY)/** John G. Palmer / 1950

Coverage: Mycorrhizal fungi, wood deterioration, fungus physiology

Worldwide

Reprints which specialize in wood-decay fungi, litter fungi, fungus pure-culture, emphasizing physiology of Homobasidiomycetes in pure culture and their ecological function in nature.

11000 citations

100 citations per year

Base format: Reprints

Retr. format: Letter/ 1 month; *or* verbal--by telephone

Retr. element: Author and title, *or* summary of information needed

Contact:
John G. Palmer
Forest Products Laboratory
P.O. Box 5130
Madison, WI 53705
(608) 257-2211 (ext.) 407
FTS (8) 364-2407

Availability: Forest Service, faculty, graduate students in forestry or forest products/ free

106 **TREE PHYSIOLOGY/** Richard E. Dickson / 1960-1962

Coverage: Wood formation, translocation, water relations, mineral nutrition

Worldwide, primarily North America

Oriented toward translocation, photosynthesis, plant hormones and other topics that affect growth, development, and wood formation. Peripheral areas are water relations (particularly effects of flooding), mineral nutrients of trees, and analytical techniques.

6750 citations

200 to 300 citations per year

Base format: Bibliographic citations, keywords, abstracts, annotations, reprints, published reference bibliographies in same fields

Retr. format: Photocopy / 2 weeks

Retr. element: Author only, *or* author and title, *or* summary of information needed, *or* author and title and date

Contact:
Richard Dickson
North Central Forest Exp. St.
P.O. Box 898
Rhinelander, WI 54501
(715) 362-7474
FTS (8) 362-1012

Availability: Forest Service, faculty, graduate students/ reproduction costs plus postage

107 **TROPICAL FORESTRY/** Institute of Tropical Forestry Library / 1940

Coverage: Puerto Rico, tropical forestry, tropical silviculture, tropical timbers, tropical ecology

Worldwide, primarily tropical areas

Collection is maintained to serve the research scientists working at the Institute. It is a research unit of the Southern Forest Experiment Station.

3000 or more citations

200 or more citations per year

Base format: Author and title references, reprints

Retr. format: Photocopy or letter/ 2 weeks; *or* verbal--in person at site of data base

Retr. element: Author and title, *or* keywords, and source of publication [some citations are filed under geographical location]

Contact:
JoAnne Feheley, Library Technician
Institute of Tropical Forestry
P.O. Box AQ
Rio Piedras, PR 00928
(809) 753-4335
FTS (8) 967-1221

Availability: Forest Service, faculty, graduate students, and Puerto Rico Governmental agencies/ reproduction costs plus postage

108 **UNISORT/** William McCambridge / 1959

Coverage: Forest insects, bark beetle, mountain pine beetle, ecology

North America

Published material on bark beetles relating to life histories, habits, development in relation to food and temperature, natural control agents, attractants (pheromones), chemical control, and host protection.

400 citations

15 citations per year

Base format: Bibliographic citations, abstracts, summaries of data

Retr. format: Photocopy / 1 week

Retr. element: Summary of information needed

Contact:
William F. McCambridge
Rocky Mountain Forest and Range Exp. St.
240 West Prospect Street
Fort Collins, CO 80521
(303) 221-4390
FTS (8) 323-1245

Availability: Forest Service, faculty, graduate students in fields related to forestry or forest products/ free

109 **WATERSHED MANAGEMENT AND HYDROLOGY/** Walter F. Megahan / 1960

Coverage: Hydrology, watershed management, water quality, stream flow, sedimentation

Worldwide

Primarily material dealing with forest hydrology and the effects of land uses on the hydrologic function of forest lands with emphasis on geology, land form, soils, vegetation, and climate with respect to erosion and sedimentation.

2500 citations

100 citations per year

Base format: Bibliographic citations, keywords, abstracts, reprints

Retr. format: Photocopy / 2 weeks

Retr. element: Summary of information needed

Contact:
Walter F. Megahan
Intermountain Forest and Range Exp. St.
316 East Myrtle Street
(208) 384-1457
FTS (8) 554-1457

Availability: Forest Service, faculty, graduate students in forestry or forest products/ reproduction costs plus postage

110 **WESTERN REFORESTATION/** William I. Stein / 1952

Coverage: Reforestation, artificial regeneration, natural regeneration

Worldwide (primarily for period of 1964-1975)

Contains titles filed by relatively broad subject matter headings only. The wider collection titles pertinent to any phase of reforestation in the western U.S. and Canada were listed annually and published. Reprints of published lists are available.

10000 citations

300 citations per year

Base format: Bibliographic citations, abstracts, annotations

Retr. format: Verbal--in person at site of data base

Retr. element: Summary of information needed

Contact:
William I. Stein
Pacific Northwest Forest and Range Exp. St.
3200 Jefferson Way
Corvallis, OR 97331
(503) 757-4363
FTS (8) 420-4363

Availability: Forest Service, faculty, graduate students, and others/ free [Data base limited to those who are prepared to search it for themselves.]

111 WESTERN SPRUCE BUDWORM/ Dave Fellin / 1972-1973

Coverage: Western spruce budworm

Rocky Mountains West and Pacific Northwest

Basically represents an up-to-date bibliographic file on the genus *Choristoneura*, including ecologic, taxonomic, and some abstracted references.

1240 citations

20 to 25 citations per year

Base format: Author and title references, bibliographic citations, abstracts, keywords

Retr. format: Computer printout/ 1 week
System used: FAMULUS
Computer center: Washington State Univ. Comput. Cent.
Compatible with: IBM 360-370

Retr. element: Author only, *or* title only, *or* author and title, *or* keywords

Contact: Dave Fellin
Intermountain Forest and Range Exp. St.
Drawer G University of Montana Campus
Missoula, MT 59801
(406) 329-3535
FTS (8) 585-3535

Availability: Forest Service, faculty, graduate students, and others/ reproduction costs plus postage

112 WHITE-TAILED DEER-TIMBER MANAGEMENT COLLECTION/ RWU-SO-1751 / 1954

Coverage: Deer forage, deer habitat, deer nutrition, modeling, range, timber-stand improvement

Southern States

References covering white-tail deer habitat requirements, timber management in relation to deer habitat management.

383 citations

(Unrecorded number of citations per year)

Base format: Bibliographic citations, abstracts, keywords

Retr. format: Computer printout/ 2 weeks
System used: FAMULUS
Computer center: Stephen F. Austin Univ. Comput. Cent.
Compatible with: Honeywell CP 5

Retr. element: Author and title, *or* keywords, *or* summmary of information needed

Contact: Lowell K. Halls
Southern Forest Exp. St.
P.O. Box 7600
SFA station
Nacogdoches, TX 75962
(713) 569-7981
FTS (8) 749-1011

Availability: Forest Service, faculty, graduate students, and forest related industries/ free until cost of printouts becomes too great

113 WOOD ANATOMY RESEARCH/ J. Thomas Quirk / 1963

Coverage: Wood chemistry, cell structure (wall density and anatomical measurements), environmental effects

Worldwide

Primarily oriented toward environmental effects on wood cell anatomy, that is, irrigation, fertilization or other extrinsic factors that affect cell wall thickness, shape, or length.

3000 citations

30 to 50 citations per year

Base format: Bibliographic citations, abstracts, keywords, annotations

Retr. format: Photocopy or letter/ 2 weeks; *or* verbal--by telephone

Retr. element: Author and title, *or* keywords, *or* summary of information needed

Contact: J.T. Quirk
Forest Products Laboratory
P.O. Box 5130
Madison, WI 53705
(608) 257-2211
FTS (8) 364-2294

Availability: Forest Service, faculty, graduate students, and others/ free

114 WOOD AND BARK EXTRACTIVES/ John W. Rowe / 1900

Coverage: Tannins, phenolic resins, naval stores, tall oil

Worldwide

Data includes information on the chemical structure, amounts, and significance of extraneous components found in wood and bark, and on the commercial significance of these components as well as their effects on the utilization of wood

25000 citations

1000 citations per year

Base format: Bibliographic citations, abstracts, annotations

Retr. format: Letter/ 2 weeks; *or* verbal--by telephone or in person at site of data base

Retr. element: Keywords (species)

Contact:
John W. Rowe
Forest Products Laboratory
P.O. Box 5130
Madison, WI 53705
(608) 257-2211 (ext.) 269
FTS (8) 364-2269

Availability: Forest Service, faculty, graduate students, and others/ free

115 WORKING TOOL FILE OF RWU-1105/ Scientists of RWU-1105 / 1950

Coverage: Soil science, hydrology, plant ecology, silviculture, forest mensuration

North America

Includes most topics in Oxford Decimal Classification categories, (1) Factors of the Environments, (2) Silvicuture, and (5) Forest Mensuration. Also includes Increment, development and structure of stands, surveying and mapping.

5000 citations

200 citations per year

Base format: Bibliographic citations, reprints

Retr. format: Letter/ 2 weeks; *or* verbal--by telephone or in person at site of data base

Retr. element: Author and title, *or* keywords (Use: Oxford System of Decimal Classification for Forestry)

Contact:
Project Leader, RWU-1105
Southern Forest Exp. St.
SPO Box 1290
Sewanee, TN 37375
(615) 598-5854
FTS (8) 222-3011

Availability: Forest Service, faculty, graduate students in forestry or forest products/ free

116 WORLD DIRECTORY OF FOREST PATHOLOGISTS AND ENTOMOLOGISTS/ IUFRO / 1974

Coverage: Forest pathologists, forest entomologists

Worldwide, except USSR and mainland China

Includes the interests of repondents by tree, pathogen, and insect genera, and by more than 100 subject matter categories. The first edition contains over 1300 names.

2000 citations

(New entries will appear in 1980)

Base format: Names and addresses arranged by subject

Retr. format:
Computer printout/ 1-3 weeks
System used: 9-track 800 BPI
Computer center: Univ. Minn. Comput. Cent.
Compatible with: IBM 360

Retr. element: Author only, *or* subject matter interest codes particular to this directory

Contact:
Harold O. Batzer
North Central Forest Exp. St.
1992 Folwell Avenue
St. Paul, MN 55108
(612) 646-0841
FTS (8) 784-0310

Availability: Forest Service, faculty, graduate students, and others/ reproduction costs plus postage. [Mailing labels are available at 4 cents each; programming time is approx. 15 minutes.]

117 **ZTREX (TREE EXTRACTIVES)/** Duane F. Zinkel / 1961

Coverage: Naval stores, tall oil, pine, resin acids, rosin

Worldwide

Information on the quantitative composition, distribution, significance, chemical structure and chemical reactions and properties of naval stores and related components found in wood and other tissues. Utilization and statistical data are also collected.

10000 citations

300 citations per year

Base format: Bibliographic citations, abstracts

Retr. format: Photocopy or letter/ 1-2 weeks; *or* verbal--by telephone or in person at site of data base

Retr. element: Summary of information needed

Contact:
Duane F. Zinkel
Forest Products Laboratory
P.O. Box 5130
Madison, WI 53705
(608) 257-2211 (ext.) 464
FTS (8) 364-2464

Availability: Forest Service, faculty, graduate students, and industry/ free

The Forest Service of the U.S. Department of Agriculture

. . . Conducts forest and range research at more than 75 locations from Puerto Rico to Alaska and Hawaii.

. . . Participates with all State forestry agencies in cooperative programs to protect and improve the Nation's 395 million acres of State, local, and private forest lands.

. . . Manages and protects the 187-million-acre National Forest System for sustained yield of its many products and services.

The Pacific Southwest Forest and Range Experiment Station

represents the research branch of the Forest Service in California and Hawaii.